History
of
RADIO TELEGRAPHY AND TELEPHONY

WRITTEN AND ILLUSTRATED BY

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PREFACE

IN the compilation of this history the author has endeavoured to collect reliable data, and not being (at the time of writing) professionally attached to any commercial wireless interest he believes that the book contains a quite unbiased review of the historical aspect of the subject. Should any inventors feel that they have had unjust or in any way mistaken treatment, they may rest assured that the author had no ulterior motive and has no wish other than to be perfectly fair and candid. He would welcome any information which would assist him in being accurate or in righting any wrong when revising for a future edition.

The book is intended to provide a useful work of reference wherein will be found many now almost forgotten "wireless" schemes and inventions. Full references will be found at the end of the book which will enable the reader to obtain first-hand information of most of them should he so desire. Many of these early inventions, though of little practical use in their present form, are exceedingly ingenious and well worthy of careful consideration by the modern experimenter, who may find ideas therein which he can apply to some new invention.

In order that the non-technical reader may have a wider understanding of the principles involved in these historical experiments a foreword is provided explaining briefly the modern view of electricity and its relation to matter and the ether. It should be borne in mind that the conception of electricity held by the early experimenters was of a much more vague and nebulous character, and many of the phenomena which they had so much difficulty in explaining are more understandable to the modern student, though, of course, he in his turn is confronted with other and far more complicated problems—a penalty always attendant upon the advance of knowledge. The finite mind can never hope fully to understand the infinite.

G. G. BLAKE.

Richmond.

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N.B.—In the above list of illustrations, and throughout the book, the Author has endeavoured to give acknowledgment to all authors and publishers from whom he has borrowed illustrations. Should an omission have occurred he would welcome notification so that it could be rectified in future editions.

HISTORY *of* RADIO TELEGRAPHY *and* TELEPHONY

A FOREWORD

The Modern Conception of Electricity and its Relation to Matter and the Ether.

IN order to account for certain phenomena scientists are in the habit of constructing postulates or theories, which they are equally ready to discard or replace by others as soon as they find some fact which does not fit in with their scheme of things, or discover some more plausible theory.

In order to explain light, X-rays, radio-telegraphy, etc., we believe there must be some omnipresent medium which, though invisible, is capable of wave motion. This infinite ocean which we have named "The Ether" fills all space. **Clerk Maxwell** long ago predicted that it should be possible to create wave motion in the ether by electrical disturbances, and, as will be seen from the perusal of this history, **Hertz, Lodge,** and others actually showed how suitable disturbances can be produced.

From the work of **Dalton, Crookes, Röntgen, Rutherford, J. J. Thomson, Bragg,** and many others we know that matter is not so solid as it seems—X-rays show us that our bodies and other objects (which we have always considered to be quite solid) are transparent; the rays can pass through them with ease, so that when an object feels quite solid to the touch we are deceived by our senses. As **Einstein** points out, everything is relative. Everything, from the stars in the heavens on the one hand to electrons on the other, can be said to belong to some certain order of magnitude. For instance, we should not compare the fastest movement of a man's arm to the speed at which light travels (186,000 miles per second). Compared with that stupendous speed, the arm at its fastest is practically standing still; each belongs to an entirely different order of magnitude. We talk of 1,000 oranges, but we should not speak of 1,000 specks of dust; we should probably measure dust by the ounce, as it belongs to a different order of magnitude.

Let us consider the smallest visible speck of chalk dust. This is composed of a large number of molecules of Calcium Carbonate ($CACO_3$), a single one of which represents the smallest possible sub-division we could make for it to retain its characteristic properties. If we divide the Calcium

Carbonate molecule into its component parts we should find that it was made up of a number of atoms of various elements, together forming one geometrical group; and again, if we examined the composition of each atom we should discover that it was not solid, as we had supposed, but that it was in some respects like our solar system, having a tiny nucleus or "sun" at its centre and a number of tiny negative entities (electrons) around it, which (if each be considered by its own standard of magnitude) are as far removed from the nucleus as are the planets from our sun. The nucleus itself is believed to be made up of a number of positively charged entities known as protons and a certain number of fixed negative particles or electrons, and it is the number and grouping of these fixed electrons and protons which give to an atom those chemical properties by means of which we are able to distinguish it from the atom of another element.

Einstein's Theory of Relativity is very helpful when we are trying to get some conception of things belonging to an entirely different order of magnitude. Think for a moment of a world so remote from this earth that it takes light 130 years to reach it; if its inhabitants possessed a telescope sufficiently powerful to enable them to see the people moving to and fro upon our earth they would at this moment be witnessing some scene during the French Revolution: we should require a magnification of an order comparable to that of their telescope in order to see electrons. **Sir Oliver Lodge** once said that there are "as many atoms in a glass of water as there are glasses of water in the Atlantic Ocean," and there are so many electrons in a 10-ounce glass that if Adam had been provided with the means of removing them at the rate of two per second, and had lived on through the ages working night and day, they would not nearly all have been removed by now. ?!

We believe from the fact that X-rays travel so easily through matter that the relatively vast spaces in and between the atoms are filled with ether, as are the interplanetary spaces in our universe. If we could magnify a speck of dust to about the size of our earth, that portion of it which we could see would probably look very much like the sky on a dark night and would appear to be mostly space, with nuclei and electrons dotted about like stars and planets.

Let us think for a moment of a short length of copper wire; this, according to our present conception, is built up of groups

of molecules each of which is composed of copper atoms, and possibly atoms of elements which have been added to harden the wire, and in addition to the electrons and protons forming the nucleus of each atom there are present around them a number of planetary electrons. These (by the application of an electro-motive force supplied from a battery or other source) can be dislodged from their nuclei and caused to travel along the interatomic spaces. Their movement throughout the length of the wire constitutes what we call an electric current. When an electron is moved it creates a strain or tension in the ether in its neighbourhood which we term an electric field. Think for a moment of a large block of jelly (as shown in Fig. 1 A) on which rest three small discs, 1, 2, and 3; if disc 1 is gently pressed downwards the jelly in its immediate vicinity will be strained, as represented in Fig. 1 B, and disc No. 2 will also be moved down out of its normal position; the strain, however, will be quite local, and disc 3 at the far end of the jelly will not be affected. If the pressure be slowly removed the strain will be relieved and discs 1 and 2 will resume their normal position; these strains are comparable to electro-static strains in the ether.

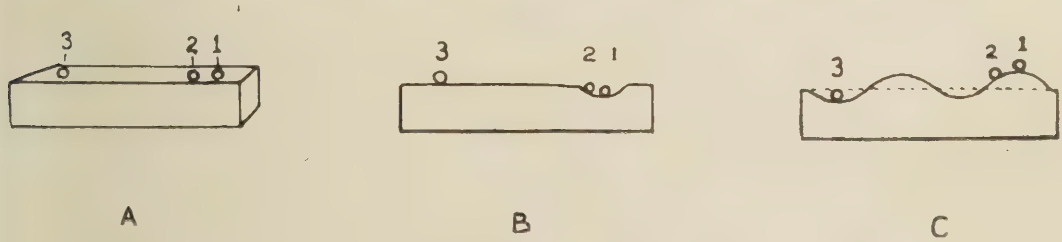

FIG. 1. Illustrating the production of wave motion.

Now let us press disc No. 1 downwards and then suddenly release it. It will (owing to the elasticity of the jelly) fly back to its normal position with such an impetus that it will overshoot the mark, and the jelly will bulge upward, as depicted in Fig. 1 C, and will continue to oscillate in this manner above and below its normal position until all the energy supplied to it by the original pressure has been expended. These movements will cause the entire jelly to assume a state of wave motion, and it will be seen that disc 3 also oscillates up and down. Hertzian waves employed in radio-telegraphy are created in a similar way to this by the oscillations of electrons up and down the transmitting aerial. When the electro-magnetic waves in the ether thus created reach the receiving aerial the electrons therein are caused to oscillate,

and it is the movement of the latter that constitutes the current which operates the receiving instruments. We must bear in mind the order of the magnitudes with which we are dealing. These etheric waves travel at the speed of light, *i.e.* 186,000 miles per second; the frequency of the oscillations of the electrons must therefore be of a high order before wave motion is created. For instance, we cannot create wave motion in the ether by holding a charged rod in the hand and moving it about; it is true that we should be causing electrons to oscillate, but their movement would be relatively so slow that only static strains and effects would be produced.

The early experimenters in wireless telegraphy knew many of the laws governing electrical action: they knew, for instance, that if two bodies are negatively electrified they repel one another, as also do two positively charged bodies. They also knew that an attraction exists between two bodies oppositely electrified. According to our modern conceptions these phenomena can be accounted for as follows: In its normal state matter is built up of positive nuclei and electrons, each creating certain strains in the ether; but these forces are balanced within the substance of the material so that no external strains are observable. If, however, we add a number of electrons to those normally present, as each electron represents a charge of negative electricity the substance acquires an abnormal negative charge which, in its endeavour to escape, strains the surrounding ether. If we bring a second negatively charged body near to it, the two bodies repel one another (they both resist the addition of electrons).

Conversely, if we remove electrons from a body in its normal state its forces will become unbalanced and it will exhibit positive electrification, and a second positively charged body will be repelled if brought near to it. If a negatively charged body is placed in the vicinity of a positively charged one they will attract one another, since the latter requires the electrons which the other wishes to reject.

This foreword is not intended to be an adequate exposition of the electrical phenomena to be met with in the following pages, and reference is recommended to the many books which have been written in explanation of the laws governing electricity and magnetism, most of which were well known in pre-radio days. The object has been, as it were, to open the window to the flood of knowledge which lies beyond.

CHAPTER I.

The Growth of Electrical Signalling Systems.

PROBABLY the first feasible suggestion of the employment of electricity for the wireless transmission of signals is to be attributed to **Professor Steinheil**, of Munich, in 1838, at which date this history commences. It may be well, however, briefly to recall the names of those great scientists who discovered the laws governing electricity, and who, by their work and observation, first brought this branch of science to a sufficiently advanced state for Radio-telegraphy to be even thought of.

The exact date at which the first observations of electrical phenomena were made is unknown, but they are usually attributed to **Thales**, who was born at Miletus, in Greece, in the year 640 B.C., and who died in 548 B.C. (1)

He is said to have noticed that amber, if rubbed, had the power of attracting light bodies. The Greek word for amber was "Elektron," hence our word "Electricity."

No more appears to have been known about electricity until the reign of Queen Elizabeth, when **William Gilbert**, of Trinity, near Colchester, discovered (in about the year 1600) that many other substances could be electrified by friction. He wrote a book on Magnetism and Attractions between Bodies. This was probably the first book written dealing with electrical phenomena. Practically all our electrical knowledge has been acquired since that date.

As this book makes no pretence of being a History of Electricity I will only mention a few of the best known workers. **Stephen Grey**, in 1729, discovered the difference between conductors and non-conductors or insulators (2)

Whilst experimenting to see how he could send a current along a metal line he found that if he substituted a metal suspension for the silk threads he had previously employed his current was lost, thus showing that the silk threads had been acting as insulators.

The **Leyden Jar** (3). The condenser, which in one form or another plays so important a part in modern Radio-telegraphy, was discovered accidently in 1746 by **Cuneus**, a pupil of **Muschenbroeck**, an eminent philosopher of

Leyden, who, trying to electrify water, employed for this purpose a glass flask which he held in his hand while a chain from the conductor of a frictional machine dipped into the water. When the experiment had been in progress for some time, wishing to disconnect the water from the machine, he caught hold of the chain and received such a shock that for two days he was quite incapacitated.

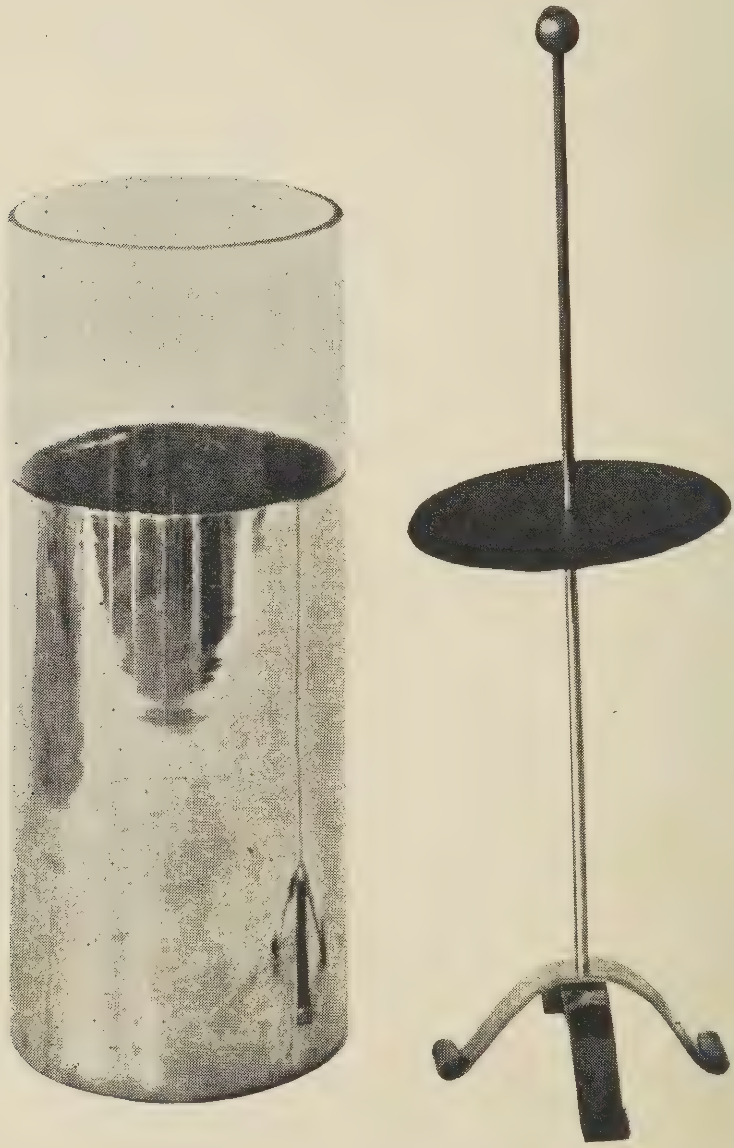

FIG. 2. A LEYDEN JAR.

This comprises a glass jar having an inside and outside coating of tinfoil. The rod on the right is for making contact with the inside coating In the flask of Cuneus water constituted the inside coating and his hand the outer one.

Franklin's Results.—**Benjamin Franklin,** a citizen of America, connected two wires, one to either coating of a Leyden Jar, their free ends being separated only by the space of about one inch. Between these wires he suspended by a silk thread a pith ball which oscillated from one wire to the other until the jar had lost all its electricity. In 1752, during a thunderstorm, he flew a silk kite on a wet string, insulated at its lower end by a short length of silk ribbon, and by drawing sparks from the string to a metal key which he held in his hand, established the identity between lightning and electricity, and as a result suggested the erection of lightning conductors. Many books have been written on the work of **Cavendish, Joule, Coulomb, Galvani, Volta, Ampère, Ohm, Faraday,** and a host of others, whose brilliant researches have made Electricity the servant of man, and have paved the way to Radio-telegraphy.

The Earth Return.—In 1838 Professor **C. A. Steinheil,** of Munich (4 to 4d and 5), carried out a test in line telegraphy between Nuremberg and Fürth, endeavouring to use the railway lines in the place of properly insulated telegraph wires. This proved a failure, but it led to a most important discovery. Rightly attributing his non-success to leakage of electricity through the earth between the rails, the idea occurred to him that as the earth appeared to be so good a conductor of electricity it might possibly be employed in place of the return wire, which had been used up to that time. This experiment was tried and proved entirely successful, and it is undoubtedly one of the most important contributions towards successful telegraphy. He also invented a telegraph alphabet, which, like that of **Morse,** was made up of two elementary signals in different combinations.

The first diagram in Fig. 3 represents the old double line telegraph, as employed before 1838. B is the battery, K the key at the sending end to make and break contact, G a galvanometer, or other needle instrument, used to record the signals at the receiving end of the lines. The second diagram in Fig. 3 represents **Steinheil's** discovery of the earth return, and the third diagram is a water analogy, in which the water represents the free electrons in the earth. The pump represents the battery, a length of pipe represents the telegraph line, and a water wheel the receiving instrument. When the pump is turned on water is drawn from the ocean at the pump end of the pipe, and after passing along the tube falls over the

water-wheel and makes it move, finally returning into the ocean again so that its level remains constant.

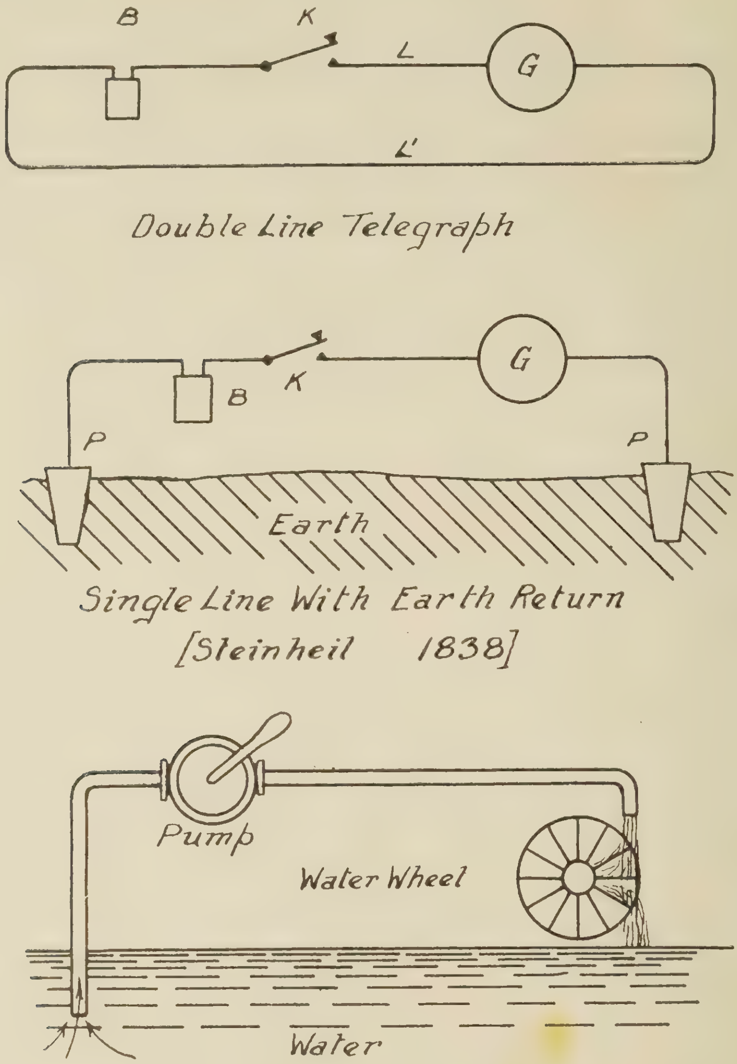

FIG. 3. Illustrating the evolution of the earth return, with a water-wheel analogy.

After the discovery of the earth return **Steinheil** continued his experiments and endeavoured to trace out the area covered by the current as it returned through the earth. He succeeded in detecting weak currents, which he picked up in another circuit having no metallic connection with the transmitting circuit. The following are a couple of quotations from his own account of these experiments. (5) "For distances up to 50ft. I have found the possibility of such electric communication by experiment. For greater distances we can only conceive it possible by augmenting the power," etc., etc. (then follow a number of technical details); "it only

holds good, however, for small distances, and we must leave it to the future to decide whether it will ever be possible to telegraph to great distances entirely without metallic connections."

MORSE, 1842.—**S. F. B. Morse** (4a, 4b, and 9), Superintendent of Telegraphs to U.S.A. Government, when giving a demonstration of line-telegraphy at the request of the American Institute of New York, between Governor's Island and Castle Garden, a distance of one mile, had the demonstration entirely spoiled owing to a vessel weighing its anchor and in so doing cutting his submerged cables. Owing to this accident the idea occurred to him that possibly water itself might be employed to carry the electricity across the river without any metallic conductors.

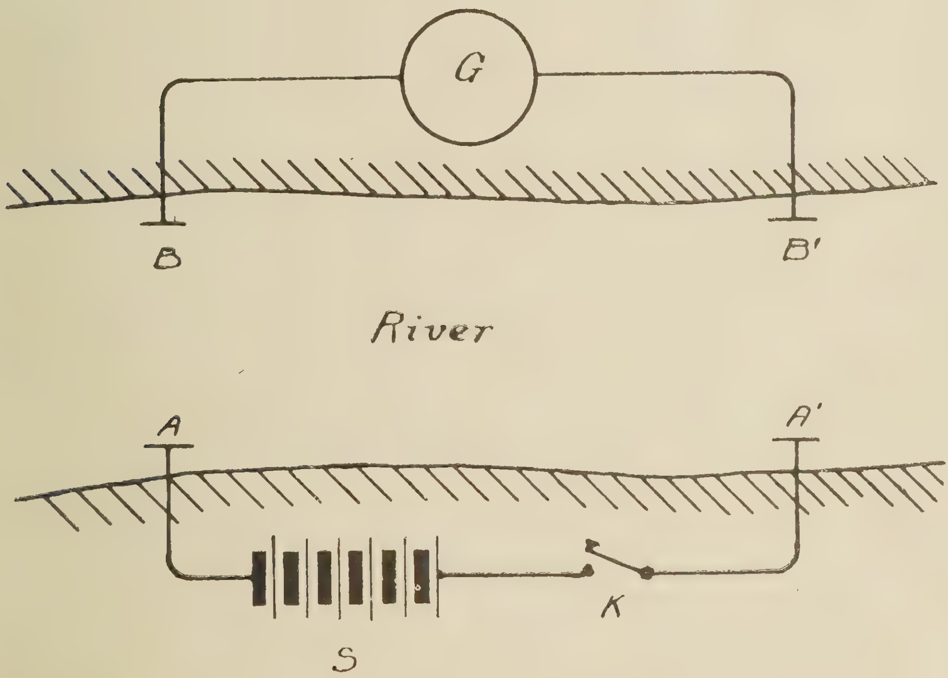

FIG. 4. Illustrating Morse's original system of telegraphing across a river.

During the same year, on December 16th, 1842, he successfully transmitted current across a canal at Washington, the distance bridged being 80ft. Fig. 4 shows the method he adopted. On each side of the canal he had insulated line wires, to the ends of which were connected large copper plates A, A[1], B, B[1], submerged in the canal. On the transmitting side he had a battery S, and Morse key K (of his own invention), and on the receiving side he placed a galvanometer in series with the

insulated line. He conducted a series of tests, placing the plates on each bank of the canal at different distances apart up and down stream, and found that, provided the plates were separated by a distance greater than the width of the canal, a reading could be obtained on the galvanometer. In 1845, working in conjunction with **Vail** and **Rogers** (his assistants), he succeeded by the same method in signalling across the Susquehanna River at Havre-de-Grace, a distance of almost one mile. (6)

A very full and interesting account of the life and work of Morse is given in a two-volume book written by his son, **E. L. Morse,** 1914, entitled "Samuel F. B. Morse, his letters and journals," in which it is claimed that he was the original inventor of the Electro-Magnetic Telegraph (7, 93, 4). It is interesting to note that during the first 30 years of his life Morse devoted himself to art. In 1813 he exhibited a picture in the Royal Academy. He devoted himself to the study of electricity after attending a course of lectures on Electricity and Magnetism by **Professor Dana,** at the New York Athenæum, in 1826. Having heard that **Benjamin Franklin** had experimented and shown that "electricity passes instantaneously over any known length of wire," Morse foresaw that it might be used for signalling to great distances, and before he had invented his telegraph he devised, almost by inspiration, his "Morse alphabet," which, with slight variations, is in universal use at the present day for telegraphy and radio-telegraphy. Another interesting fact, and one not very well known, is that whilst in Paris in 1838 he met **Daguerre,** who explained to him how far he had succeeded in perfecting the daguerrotype process, and in America he shares with **Professor Draper** the honour of being the first to photograph living persons.

In Great Britain, in 1845, **Wm. F. Cook** and **Chas. Wheatstone** carried out similar experiments to those shown in Fig. 4, using an instrument designed by **Wilkins,** which was a forerunner of **Lord Kelvin's** Siphon Recorder. Wheatstone, it will be remembered, was responsible for laying the first Channel cable to France in 1850 (the same year in which the first trans-Atlantic cable was laid). He also patented a needle telegraph, and there is some doubt as to whether this was not prior to that of Morse.

Lindsay's Experiments.—In 1843 **James Bowman Lindsay** carried out a series of experiments very similar to those of

Morse, across the river Tay where it was three-quarters of a mile wide, and his greatest achievement was a distance of two miles—from Dundee to Woodhaven. A few facts concerning this remarkable man and his other achievements may be of interest. He was born in 1799 at Carmylie, where he learned weaving. Being exceedingly poor, he educated himself as best he could, attending St. Andrews University as a student and working at his trade during the college recesses. He worked hard and he worked alone, often almost on the border of starvation, and could only afford to rent one room. He predicted the universal adoption of electricity for lighting, heating, and power. In 1829 he was lecturer on mathematics at the Watt Institution. His poverty can be better realised when we know that he gladly accepted the appointment of teacher in Dundee prison in 1841, at a salary of £50. In 1858, on the recommendation of the Queen, he was granted a pension of £100 per annum. His death was very sad. His rooms (for now that he was in receipt of a pension he had two), in a flat near the harbour, contained piles of books from floor to ceiling. On the table, when the hand of death arrested him, lay his great work, "A Dictionary of 50 Languages," in neatly written manuscript, but unfinished. It was already a volume of ponderous bulk, the pages of which he had ruled most carefully, and methodically spaced to allow of the equivalent of each word being written in many languages. "Very pathetic was the testimony borne by that book to the old man's ambition to leave something monumental behind him, and the manner in which his hand had been stopped in the midst of his labours" (**Kerr's** Book, *loc. cit.* 9).

CHAPTER II.

The Development of the Telephone.

OF the two branches of science, Telegraphy and Telephony, the former is the older, and from the foregoing chapter it will be seen that wireless telegraphy over short distances had already been achieved when, in 1861, the first practical attempts at telephony were made by **Philip Reis**, of Friedrichsdorf. This new adjunct to science has been of the greatest utility, and still forms one of the most essential instruments in modern radio stations. A short account of the development of the telephone will therefore be useful at this point.

In 1831 **Wheatstone** showed that if the sounding boards of two musical instruments were joined together by a rod of pine wood a tune played on one was faithfully reproduced by the other.

In 1837 **G. G. Page** (of Salem, Mass.) drew attention to the musical note produced by rapidly revolving the armature of an electro-magnet in front of the poles, and he termed this effect "Galvanic Music." **Helmholtz**, by placing a tuning fork, having an adjustable contact against one of its prongs, between the poles of an electro-magnet, and by connecting the fork, the contact, and the electro-magnet in series with a battery, caused the former to vibrate and emit a musical note. In 1854 **Chas. Borseul**, of Paris, published articles on the electric transmission of speech, but his results were, so far as one can ascertain, not very satisfactory.

The fact, pointed out by **Page** in 1837, that the magnetization and demagnetization of an iron bar causes the emission of a sound led **Reis** to the discovery of the telephone. His earliest transmitter and receiver, constructed in 1861, consisted of a diaphragm of animal membrane (parchment) to the centre of which was attached by sealing-wax a small plate of platinum, on which rested a fine platinum point. The vibration of the diaphragm caused variation of the electrical resistance of this contact. His first receiver consisted of a knitting-needle, round which was wound a coil of fine insulated wire, the needle being attached to a violin which acted as a sound-box. Later he invented another telephone in the form of the human ear. Reis showed his apparatus for the first time

to the Physical Society of Frankfort in 1861, but he did not properly get over the difficulty of reproducing the three essentials in the sounds transmitted, namely, the pitch, the amplitude, and the quality. This early telephone underwent many modifications before it could be utilised for practical purposes.

S. Yeates (1865), **Wright** (1865), **E. Gray** (1874), **C. & L. Wray** (1876), **C. Varley** (1877), **Van der Weyde**, **Pollard**, and **Garnier** all worked on the subject; but the **Bell** electro-magnetic telephone receiver, based on **Faraday's** electro-magnetic discoveries, and **Hughes'** microphone finally brought telephony out of the experimental stage and supplied us with reliable instruments (12, 13, 14).

A very interesting account (in his own words) of **Dr. Graham Alexander Bell's** early career and experiments appeared in the Sydney "Morning Herald" on the occasion of his visit to Australia in 1907. Dr. Bell was a Scotchman by birth, and later became an American citizen, his grandfather and father having both been by profession teachers of deaf mutes in Scotland. Two of Bell's brothers died of consumption, and in 1870 Bell was so ill with this complaint himself that he was not expected to live more than six months.

He therefore went out to Bradford, Ontario, where he completely recovered after spending a whole year in the open air. In 1871 he went to Boston, U.S.A. At this time he was engaged in teaching deaf mutes to speak. In 1874 the idea occurred to him that his deaf and dumb pupils might be taught to interpret the wave forms of speech produced from **König's** manometric flame by means of a revolving mirror.

This apparatus consisted of a small chamber having a diaphragm at one side, through which the gas passed on its way to the flame. The diaphragm was caused to vibrate by the human voice, and produced variations in the length and brightness of the flame, which, when viewed by the aid of a revolving mirror, appeared as a wave form. These wave forms being only of a transitory nature, and wishing to obtain permanent records, he next turned his attention to the "phonautograph" of **Leon Scott.** This consisted of a cone over the smaller end of which was tightly stretched a membrane, and hinged to the edge of this was a long lever of wood, which was also connected with the centre of the membrane by a small "bridge." At the other end of the lever was fixed a short pig's bristle, which was placed just above the surface of a

sheet of glass covered with lampblack. By speaking into the cone vibrations of the membrane were set up which moved the lever and the bristle scraped a line in the lampblack, which was arranged to move beneath it.

On comparing the wave forms produced by the same sound in both pieces of apparatus he found that they differed, and he came to the conclusion that the phonautograph, which was rather a crude instrument, had distorted the vibrations. He wished to perfect it, and in considering the problem it occurred to him that its mechanism was wonderfully like that of the human ear. In order to copy the ear as perfectly as possible in the construction of a new instrument, he went to an aurist in Boston, Mass. (**Clarence J. Bake**), who obtained for him the ear of a man who had just died. Using this ear, he obtained some very beautiful tracings. He then conducted some experiments in quite a different direction. As he says in his article before cited, " Quite apart from these experiments to help me in my teaching, I had also been engaged for some years on an experiment which interested me. I was only an amateur at electricity, but I was very much struck with the idea for transmitting a great many telegraphic messages over the same wire at the same time. I called it multiple telegraphy. A great many other people have been engaged on the same sort of invention. I applied for my patent in 1875, but it is not settled yet."

His idea was (14 and 15) to transmit different musical notes, on the principle that if you strike a note on one of two adjacent pianos the corresponding string on the second piano picks up the vibration and also emits a musical note. He says, " My idea was to invent an apparatus which would be made as if you had two pianos with a great number of electromagnets, one under each string. The stage at which I had arrived in the summer of 1874 was as follows : instead of a piano, I had a whole row of steel reeds, which were each clamped at one end to the pole of an electro-magnet, each being tuned to a different pitch, and at the other end of the wire I had a second similar set. The theory I was working on was that when you have a magnetized steel reed vibrated to and fro in front of an electro-magnet you induce corresponding electrical impulses in the coil surrounding the electro-magnet. I had a number of these reeds on a number of electro-magnets, all connected on the same circuit, but tuned to different pitches. If I plucked one of the reeds it vibrated and emitted

a musical tone and created an undulatory current of electricity in the coil of the electro-magnet. This current traversed the wire and passed through all the electro-magnets at the receiving end, causing all the magnets to attract the steel reeds in front of them, and causing that particular reed which had the same frequency as the one I had plucked at the other end to respond."

He next found that he could dispense with the use of a separate electro-magnet for each reed and fix all the reeds in front of one elongated magnet. The arrangement is represented in Fig. 5.

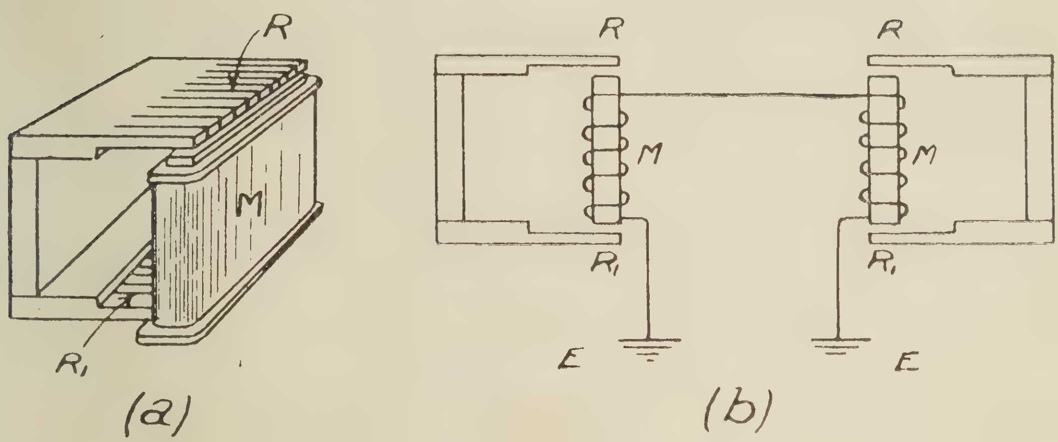

FIG. 5. Bell's Reed Telephone.

R and R1 represent the double set of steel reeds, and between them in each instrument, as shown in Fig. 5(b) is fixed the electro-magnet M. Having reached this stage in his investigations, **Bell** happened one day to be experimenting with the human ear. "I had fixed up," said he, "the ear with an artificial tube into which I could speak, the parts all moistened with glycerine water to make them mobile, and I was delighted to see the dead man's ear vibrate and a beautiful line drawn" (a wave-form tracing). "Just then, in my electrical experiments, my problem was how to move the reed in the way the ear moves during sound. It struck me that the bones of the ear were very massive in comparison with the membrane—perhaps the supple membrane could move the piece of iron in the way I wanted. All I had to do was to stretch the membrane stiff like parchment and fix the reed in the middle of it. And there was the telephone! That was the conception of the speaking telephone arrived at in the summer of 1874,

in Bradford, Canada, at my father's house. These two lines of experiments suddenly came together and made it."

Bell did not put this idea to the test until a year had elapsed. In June 1875 he was observing some experiments with an electro-magnet and a tuned reed at each end of a line. **Watson,** his assistant, was in a room at one end. He called out to Bell, who was at the other end of the line in another room, that a reed had stuck to the pole of the magnet. Bell told him to shake it free, and as he did so Bell's eye happened to be fixed on the reed at his end, and he noticed that it vibrated. A most unexpected happening, as no batteries were employed in the circuit! Obviously here was a most important effect, and they spent the whole afternoon in making the reeds vibrate in this manner. Bell got his assistant to vibrate a reed which was selected so as to be out of tune with the one at his end of the line, and still the transmitted note was reproduced. Immediately he instructed Watson to make up a membrane telephone on the lines he had suggested the year before. This was soon made, and I will describe the first trial made with the instrument, in his own words (see Bell's article in Sydney "Morning Herald," 1907):

"I well remember our crowning experiment. It was tried in a noisy workshop, Mr. Williams' electrical shop in Boston. My station was in the attic, and Mr. Watson's in the basement. We were to speak and listen by turns. He was to speak first. I listened and could not be sure I heard. It might have been anything. Then I spoke to Watson. I called 'Do you hear what I say?' A moment or two after Watson rushed up the stairs. 'I heard your voice,' he cried." It was patented in 1876 (see also reference 86), and exhibited that year at the Centennial Exhibition, Philadelphia. **Sir William Thomson (Lord Kelvin)** was present, acting as one of the judges, and, says Bell, when he got back to England he spoke of it as "the most wonderful thing he had seen in America."

(The author has not been able to trace any record of these exact words, but at the British Association meeting in 1876, at which Bell gave a demonstration of his telephone, Lord Kelvin, then Sir William Thomson, gave an account of what he had seen of Bell's telephone in America, and spoke of it as "This, the greatest by far of all the marvels of the electric telegraph.")

Fig. 6(a) shows **Bell's** first telephone, in which the membrane is attached to a reed in front of the magnet and bobbin.

Fig. 6(b) shows Bell's second telephone, in which the reed

was dispensed with and a small piece of iron attached to the centre of the membrane.

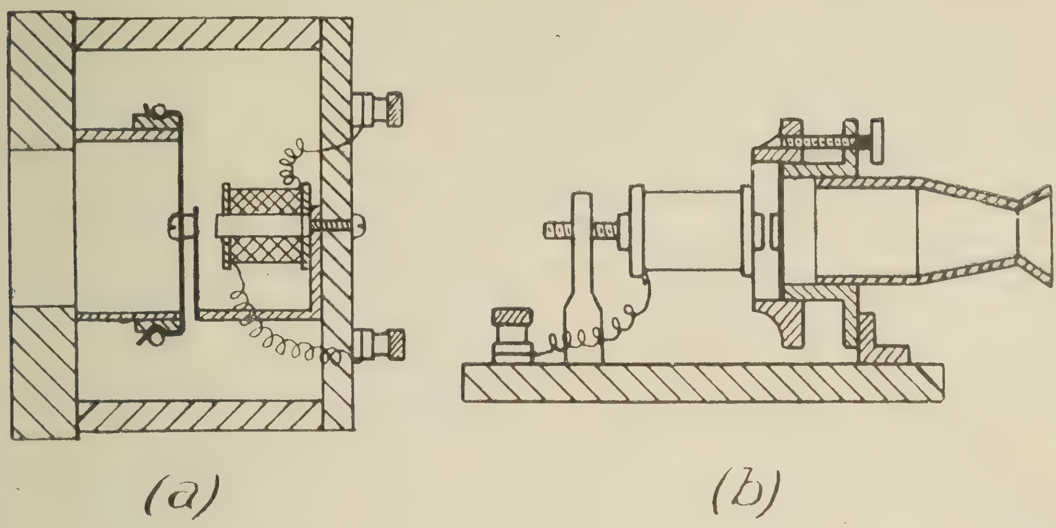

Fig. 6. Bell's Early Forms of Telephone.

In 1877 **Thos. A. Edison** produced a telephone very similar to that of Bell (86).

The invention of the electro-magnetic telephone by Bell was challenged by several claimants, including **A. E. Dolbear,**

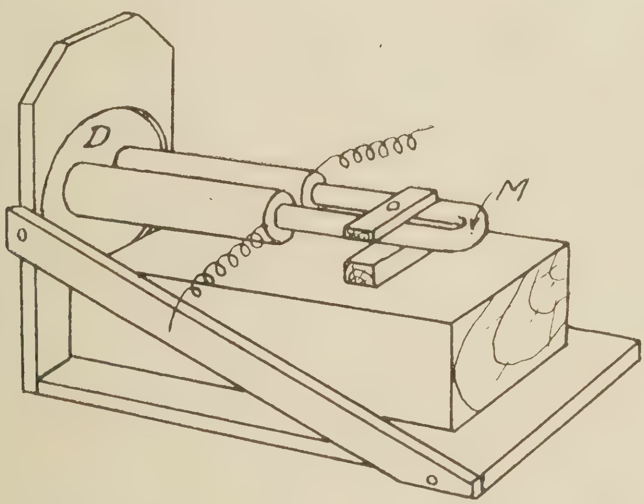

Fig. 7. Dolbear's Telephone.

who in his book, " The Telephone," published in 1878, says that his telephone, shown in Fig. 7, was invented " without

D

the slightest knowledge of the mechanism which **Bell** had used." One of these instruments was employed as transmitter and the other as receiver. D was a diaphragm of steel sheet 1/50th of an inch thick, and M was a steel magnet. **Dolbear** concludes his book with the following striking phrase : "Mechanism is all that stands between us and aerial navigation, all that is necessary to reproduce human speech in writing, and all that is needed to realise completely the prophetic picture of the 'Graphic,' of the orator who shall at the same instant address an audience in every city in the world

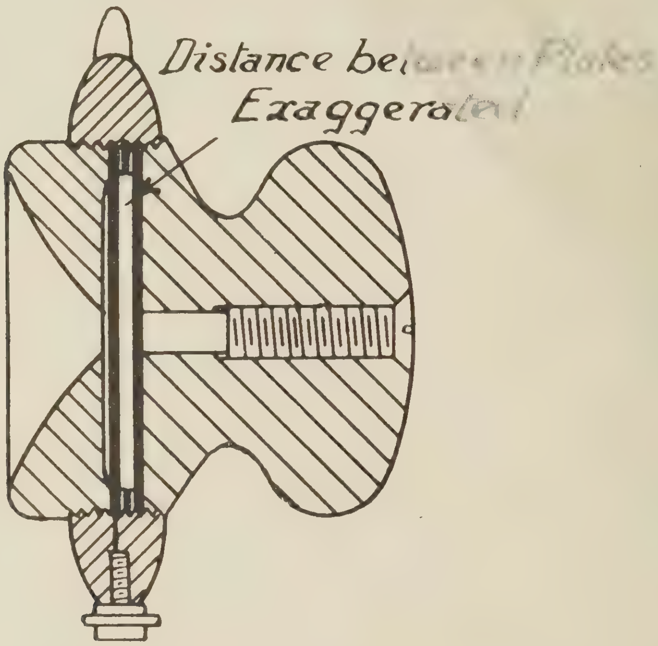

Fig. 8. Dolbear's Electro-static Telephone.

Fig. 8 shows another telephone receiver, invented by **Dolbear** in 1879 (16, 92), the electro-static telephone. This was used by him in his successful experiments in wireless telephony, described in a later chapter. It consisted of two metallic discs, brought very close together so as to form two plates of a small condenser, one connection being made to each disc.

The first disc was free to vibrate as a diaphragm, but the back disc was fixed by an adjustable screw, which also served to adjust the distance between them. The variations in electro-static strain between the discs provided the means of producing the necessary vibrations. (Dolbear was probably the first to obtain good results with a static telephone. The speaking condenser was discovered by William Thomson in 1863 (92).)

An interesting telephone on an entirely different principle to either of the foregoing was invented by **Antoine Bréguet.** The same instrument is used at each end of the line and acts as either transmitter or receiver. The point of a capillary tube A dips into a vessel T containing a solution of weak sulphuric acid, a small quantity of mercury at the bottom of the vessel acts as one electrode, making connection with one line wire L. The capillary tube A is also filled with mercury and connected with the other line wire L1. A diaphragm stretched across a small chamber, leading into the top of the capillary tube, is caused to vibrate by the voice; the pressure of the air in the capillary tube is thereby continually varied, causing corresponding differences in the level of the mercury.

If this transmitting instrument be joined to an exactly similar instrument the mercury in the capillary tube of the latter will follow the movements of that in the transmitter, the whole process being reversed, and the diaphragm of the second instrument will reproduce the transmitted sounds. This instrument can be used with or without a battery. Its action is due to the fact that for any given potential the mercury in the capillary tube assumes a definite position. A change of potential will alter the position of the mercury and, conversely, a change of height in the mercury is accompanied by a corresponding change of potential, due to electro-capillary action.*

A. PLECHER'S CAPILLARY RECEIVER.—In 1903 (800) **Plecher** made a receiver which operated on the same principle. The instrument consists of a capillary tube, or tubes, leading from the base of a closed chamber containing a quantity of mercury, the capillary ends of the tubes dipping down into a closed vessel containing a potassium cyanide solution; ear tubes are connected to the closed chamber, and when an electrical impulse passes through the capillary tubes the capillary column rises, to fall again when the impulse ceases. By this means the pressure of the air in the closed chamber is continually varied and the signals are heard.

EDISON'S ELECTROMOTOGRAPH (11,773).—**Edison's** electromotograph, Fig. 10 is another very interesting receiver, for which possibly some use may yet be found in wireless telephone reception. It consists of a cylinder of chalk or paste containing lime, caustic potash, and a small quantity of mercury acetate. When of chalk, it is moistened with potas-

* Reference should also be made to the work of **Orling** and **Armstrong** in Chapter IX

sium iodide. The cylinder is revolved slowly by clockwork. A strip of platinum rests over the top of the cylinder, causing friction as the cylinder revolves. If a current be passed from lines L, L1, through the cylinder and platinum strip it will appreciably vary the friction between them and cause a move-

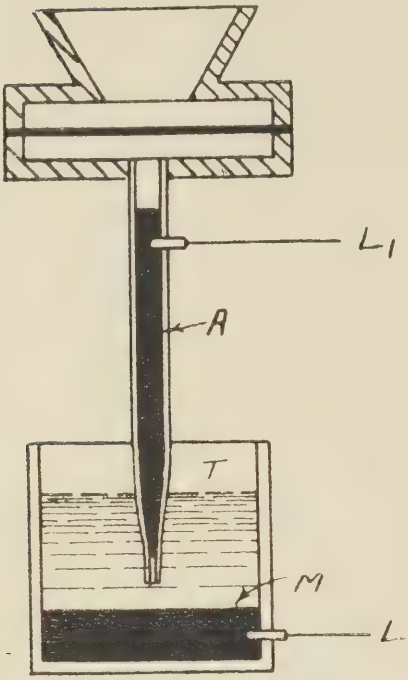

FIG. 9. Bréguet's Capillary Receiver.

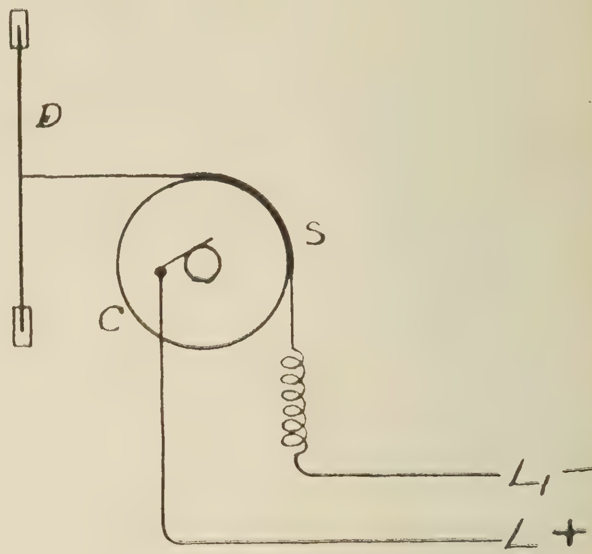

FIG. 10. Edison's Electromotograph.

ment of the mica diaphragm D, and every variation in the current will cause a corresponding variation in the movements of the diaphragm. The cylinder can be revolved in either direction, and the platinum strip acts equally well, whether arranged to pull or to push the diaphragm.

In 1880 **Preece** described a thermo-telephone receiver in a paper read before the Royal Society. This is shown in Fig. 11. It consisted of a metallic diaphragm D, to the centre of which was fastened a fine platinum wire P, 6ins. long, the tension of which was adjusted by means of a screw S. If this wire is inserted in circuit with a microphone M and battery B every variation of current will alter the temperature of the wire, thereby altering its length and causing corresponding movements of the diaphragm D. Both **Campbell Swinton** and

the **Author** have independently made use of this instrument for the reception of wireless signals, placing it in an oscillatory circuit without the employment of any rectifying detector (17).

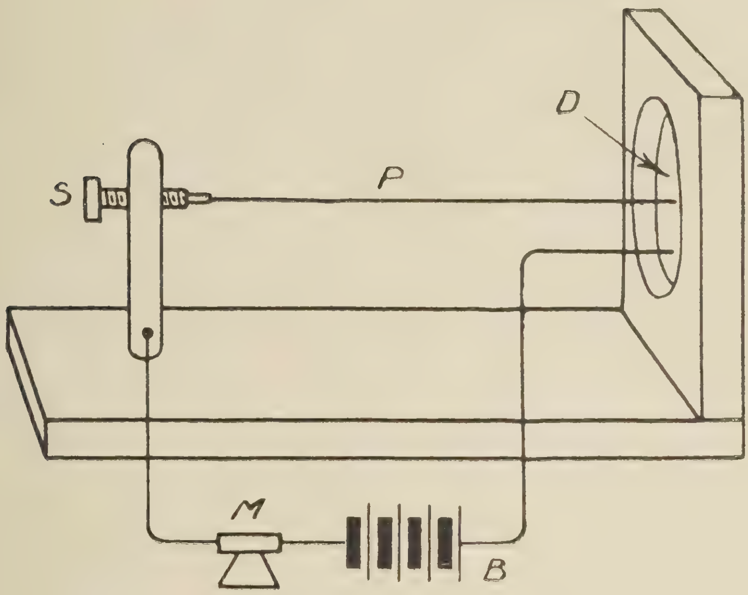

FIG. 11. Preece's Thermal Receiver.

For another form of hot-wire receiver see **Dr. Eccles'** thermophone, described in Chapter VIII. of this work. The instrument is illustrated in Fig. 12.

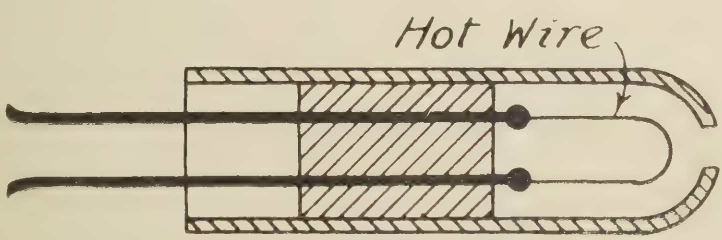

FIG. 12. Eccles' Hot-wire Receiver.

In 1887 **Professor Geo. Forbes** described some experiments before the Royal Society.* He used a red-hot wire as a

* See also **Tucker's** hot-wire microphone (396), Chapter XIII, page 204.

telephone transmitter. A fine platinum wire was included in circuit with a battery and the primary of an induction coil, the secondary of which was connected to a telephone receiver. When the wire was incandescent, words spoken towards it could be heard in the receiver owing to the change of resistance due to cooling. This transmitter was quite insensitive to mechanical vibrations.

In 1901 **A. T. M. Johnson** devised a telephone receiver which he used in connection with the **Johnson-Guyott** system, described later in this book. In place of a diaphragm in front of the magnetic poles of his receiver he employed a tuned reed or a tuning fork.

In 1910 we have the use of the tuned reed cropping up again, this time in conjunction with a diaphragm, in the now so well known telephone devised by **S. G. Brown,** and patented by him in patent No. 29833 of 1910. The receiving

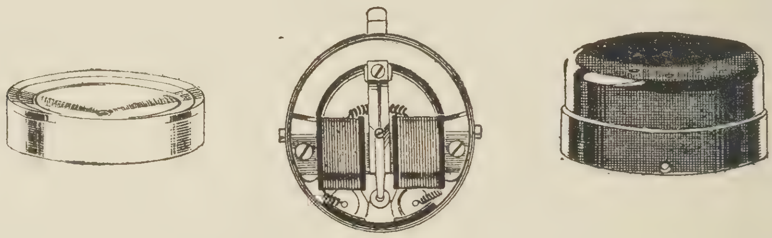

Fig. 13. Brown's Telephone Receiver. The centre figure shows the coils and the reed. The aluminium diaphragm is seen on the left and the ebonite cap on the right.

coils of this instrument are wound on the pole pieces of a permanent magnet, as usual, but the ordinary diaphragm is replaced by an iron reed (tuned to a suitable note), to which an aluminium diaphragm is screwed. This diaphragm is conical in shape, and is attached to the receiver case round the edges. Another refinement of this telephone is an adjustment which will govern the distance of the poles of the magnet from the reed. This telephone is shown in Fig. 13.

This same arrangement is employed in the construction of the **Brown** "Loud Speaker" (61).

Mercadier's Monotelephone (92) (or Tuned Telephone). —This telephone is shown in Fig. 14. It consists of a small rectangular diaphragm D, hinged on an axle A, in front of the windings round a permanent magnet M, M1, and its other end is attached to a tightly stretched wire W, tunable by means of a worm-wheel to the desired note.

THE LOUD SPEAKER OF K. W. WAGNER AND LÜSCHEN (809). Another form of loud-speaking telephone receiver is that developed in Germany by **K. W. Wagner** and **Lüschen,** and manufactured by **Messrs. Siemens & Halske.** A new principle is employed in this instrument. A strip of corrugated

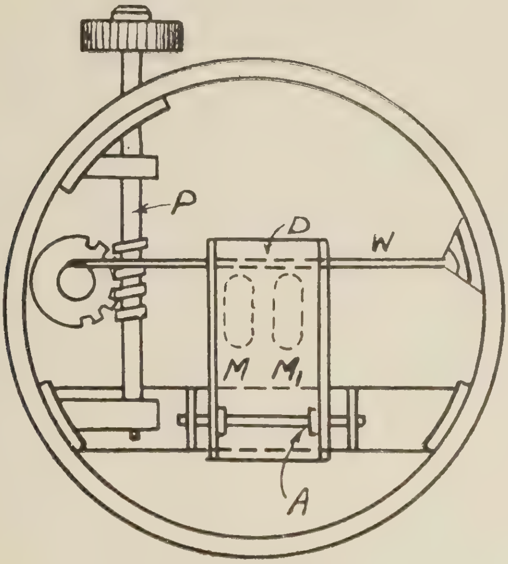

FIG. 14. Mercadier's Monotelephone.

aluminium foil, fixed rigidly at each end, is arranged between the poles of a powerful electro-magnet in such a way that the edges of the foil are opposite to the pole pieces, the latter being sufficiently far apart to allow for the width of the strip of foil between them. The amplified speech currents are passed through the foil from end to end and cause it to vibrate in a direction at right angles to the magnetic field.

ELECTRO-MAGNETIC MICROPHONE.—The same principle has been used by the inventors in the construction of a microphone. In this case the movement of the foil strip (under the influence of sound waves from the voice) in the magnetic field generates a current which is amplified and used to control radio-telephonic transmission. The principle is very similar to the **Sykes-Round** Microphone, described in Chapter XIII.

THE CARBON MICROPHONE.—In May 1878 **Professor Hughes** read a paper before the Royal Society in which he showed that a loose contact acted as a telephone transmitter, the vibrations from the voice causing corresponding variations in its electrical resistance. He termed this type of transmitter a microphone, and it has retained this name ever since.

One of the early forms of this instrument, as constructed by Hughes, is shown in Fig. 15. B is a carbon pencil which rests between two blocks of carbon C and C1. This simple instrument is connected in series with a battery and a telephone receiver.

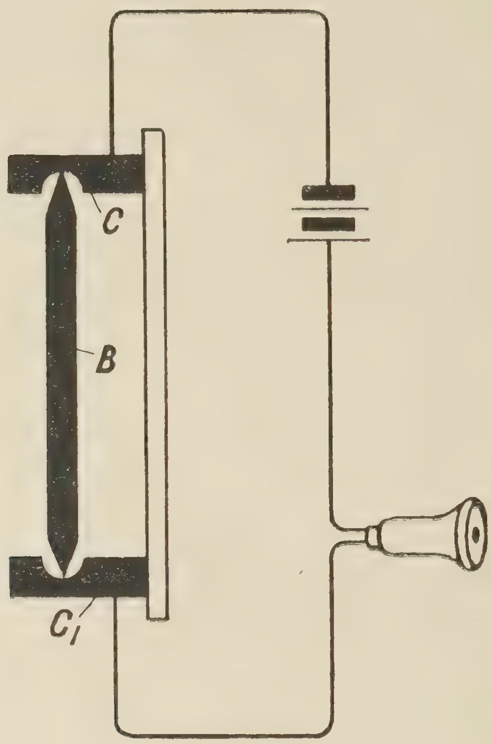

FIG. 15. Hughes' Pencil-Microphone.

In March of the same year (1878) **Edison** took out U.S.A. patent No. 203,016/78, in which he describes lampblack as a material in which variations of electrical resistance could be brought about by slight variations of pressure due to the movements of a diaphragm under the action of sound waves from the voice. He placed a disc of lampblack between a rigid metal backing and a metal diaphragm, and included it in circuit with a battery and a telephone receiver (18).

MILLER'S MICROPHONIC TELEPHONE RECEIVER.—In a paper read before the Wireless Society of London in 1921 (20) **Leslie Miller** describes a loose contact microphonic telephone receiver. It consists of two contacts, one of which is mounted in the centre of a diaphragm and the other pressing lightly against it. This microphonic contact is placed in series with the secondary of a telephone transformer and a D.C. battery of from 2 to 6 volts. Various substances may be employed as

contacts, such as Galena (lead sulphide), Fused Marcasite (iron sulphide), Carbon, etc. The treated Galena known as Hertzite also acts very well. Its action is probably due to thermal effects.

For further information on the development of microphones see footnote.*

THE JOHNSEN-RAHBEK LOUD SPEAKER.—In 1917, another form of telephone has been invented by **Messrs. Alfred Johnsen** and **Knud Rahbek,** and described by them in a joint paper read at the Institution of Electrical Engineers in May 1921 (19, 95, 235, 773). It is based on a phenomenon noted by **Dr. Elisha Gray** about 1873, and described by him in the Journal of the American Electrical Society of March 1875.

The reader should also refer to **Fessenden's** frictional receiver. An abstract of his American patent of 1913 is given in Chapter VII.

In the lecture at the I.E.E. above referred to **Johnsen** and **Rahbek** showed that if a block of metal, having a flat polished surface, be placed on the flat surface of a block of agate, slate, flint, or one of many other semi-conductive materials, the former being connected to one terminal and the latter to the other terminal of a high-tension supply, as long as the current flows a very powerful adhesive force is developed between them which ceases as soon as the circuit is broken. They showed that a voltage of 400 was sufficient (even when the resistance of the human body was included in the circuit) to enable a 2-inch metal disc to lift a block of lithographic stone weighing several pounds.

They attribute the action to electro-static attraction between the two surfaces. They have applied this principle to the construction of the loud-speaking telephone shown in Fig. 16.

*CHAPTER X. deals with

Phillips Thomas's glow discharge microphone.

Lee de Forest's gas flame microphone.

Blondel's manometric flame controller.

Chambers' flame transmitter.

Simons' microphonic arc, etc.

CHAPTER XIII. deals with :

The carbon microphones of **Berliner, Blake, Edison, Hunnings, G.P.O., Fessenden, Collins, Dubilier, Goldschmidt,** and others.

The liquid microphones of **Jervis Smith, Vanni, Majorana, Sykes,** and **Chambers.**

The condenser microphones of **Fessenden** and **Burstyn.**

The magnetic microphones of **Alexanderson** and **Sykes Round.**

The mercury vapour microphone of **Coursey,** etc.

The hot-wire microphones of **Tucker** and **Koepsel.**

A is a small cylinder of agate, which revolves slowly in the direction of the arrow, and this is connected to one line-wire L_1. D is a diaphragm, to the centre of which is attached a strip of thin metal S, which rests on the polished surface of the agate cylinder. The amount of the friction between these surfaces can be adjusted by altering the tension of spring Q. The other line-wire is attached to the metal strip. The varying currents from the telephone lines cause variations in the friction between cylinder A and strip S, which cause corresponding movements of the diaphragm D.

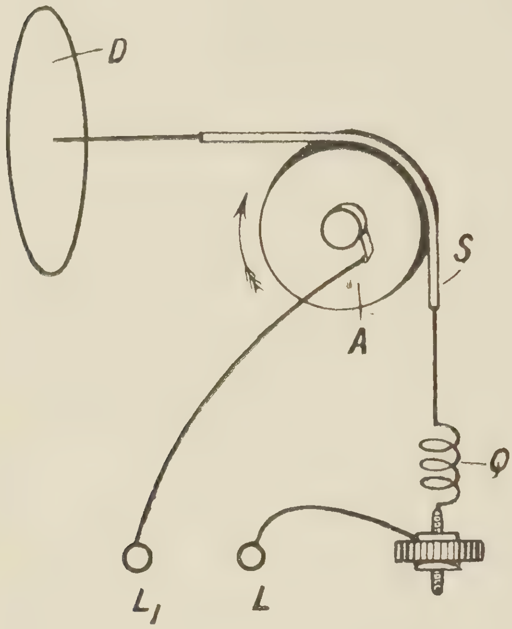

FIG. 16. Illustrating principle of Johnsen-Rahbek Loud Speaker.

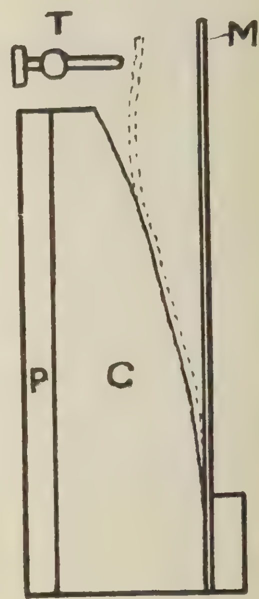

FIG. 17. Diagram of Johnsen-Rahbek Relay

THE JOHNSEN-RAHBEK ELECTRO-STATIC RELAY.—**Johnsen** and **Rahbek** have devised a relay (95), as shown in Fig. 17. It consists of a semi-conductor C (slate, agate, or other slightly conducting material). This is coated on the outside with a metal plate P, and against the other side, which has a smooth polished surface, and which tapers as shown in the diagram, is fixed a pliable smooth metal strip M. When a high potential is applied between the strip M and the plate P a powerful electro-static attraction takes place between the surface of the semi-conductor and the strip M, so that the entire length of the latter folds itself round the curved surface and comes into contact with a stud T, so closing a local circuit.

MCLACHLAN'S MAGNETIC DRUM RECORDER.—In a paper before the Wireless Section of the I.E.E. on April 11th, 1923, in which he described a new type of recording

instrument, **Dr. McLachlan** showed a very similar magnetic adhesive effect (1121).

He employed a cylindrical drum of iron with a recess in which a coil of wire was wound. The drum was caused to rotate by a motor. Over its surface rode a little iron shoe, and the attraction between the cylinder and the shoe was enormous when a small current was passed through the drum coil.

It should, however, be borne in mind that entirely different phenomena are involved in this case from the effects produced by **Johnsen** and **Rahbek,** which are electro-static.

On June 8th, 1923, **S. G. Brown** exhibited a very novel form of loud speaker which magnifies quite 30 times. It consists of a Brown telephone from which the diaphragm has been removed, and in its place, hinged to the reed, is a slender steel needle having at its free end a small disc of cork. The telephone is arranged in such a position that the needle depends from the reed in a vertical position and the cork disc lightly presses on the surface of a perfectly flat disc of plate glass arranged to rotate slowly in a clockwise direction. Two fine silk threads connect the needle to a diaphragm at the smaller end of a conically shaped horn. Normally, owing to the rotation of the glass plate and its frictional contact with the cork disc, there is a steady tension on the diaphragm. When signals or speech are reproduced by the reed of the telephone, variations in the frictional grip between the glass and the cork disc occur, with corresponding variations in the tension of the thread, which in turn causes the diaphragm to vibrate (599).

Brown, in British Patent No. 194510, has also shown that the resonance of the horns employed for loud-speaking telephones can be minimised by drilling holes to relieve the pressure at certain points in the horn where the pressure of the air waves is at a maximum. These nodal points occur at one-half, one-quarter, one-eighth, etc., of the length of the horn from its smaller end. (36).

The Magnavox Loud Speaker.—This is another very powerful form of loud-speaking telephone of American design (61). Fig. 18 is a diagram illustrating the construction of this telephone. From a diaphragm D is suspended a light coil of insulated wire C, which floats freely over the central pole piece of an electro-magnet M. The field of this magnet is made very intense by the aid of a direct current from a 6-volt accumulator B, which can be switched on or off at will by means of a switch S.

The telephone currents are applied to the moving coil C after passing through a telephone transformer T. In this instrument the vibrations of the diaphragm are unimpaired by the proximity of the magnet poles and they are able to attain to their maximum amplitude, so that the sound volume from this loud speaker can be great.

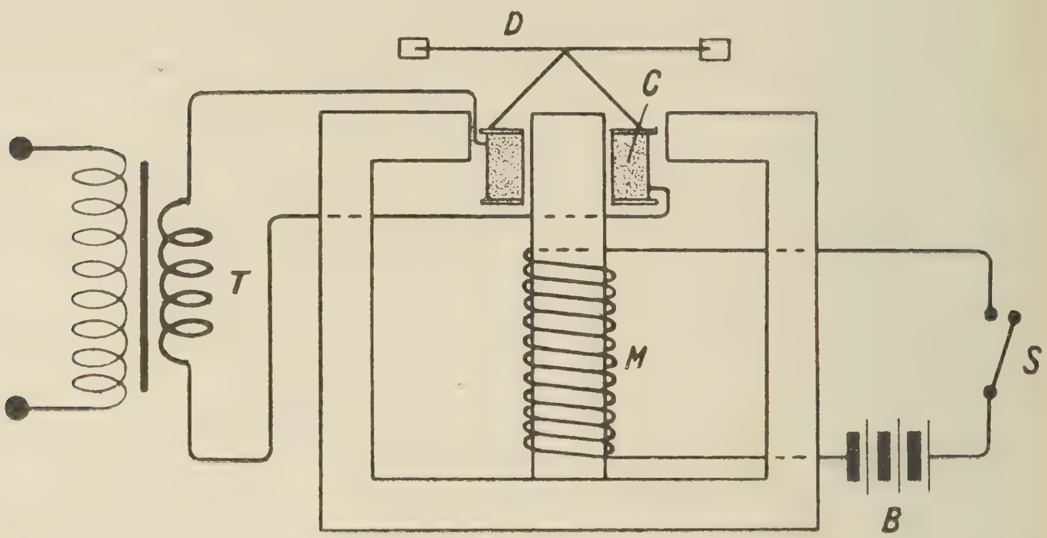

FIG. 18. Diagram of Magnavox Loud Speaker. This instrument operates on the moving coil principle.

THE WESTERN ELECTRIC LOUD SPEAKER.—In this instrument a corrugated diaphragm is employed in order to avoid, as far as possible, the trouble of predominant notes. The changes of magnetization do not act directly on the diaphragm, but upon a mechanically coupled armature the movements of which are controlled by a varying magnetic field placed at some distance from the diaphragm itself. (A diagram of this instrument is given by **Coursey** in his article on " Loud-speaking Telephones " (61).)*

THE STENTORPHONE.—This form of " loud speaker " was invented by **H. A. Gaydon** and is manufactured by **Creed & Co.** Pulsating blasts of compressed air are released into a horn by means of a valve, controlled (when used for wireless) by electro-magnetic means. The volume of sound emitted is controlled by a regulator in the air supply pipe, and enormous volumes of sound can be produced.

* On November 29th, 1923, a lengthy discussion on loud speakers was held at the Institution of Electrical Engineers, during which many of the best known types were discussed both in theory and practice. (See Journal of I.E.E., Vol. lxii., p. 265).

When used in conjunction with a gramophone the valve is worked mechanically by the vibrations from the gramophone needle (804).

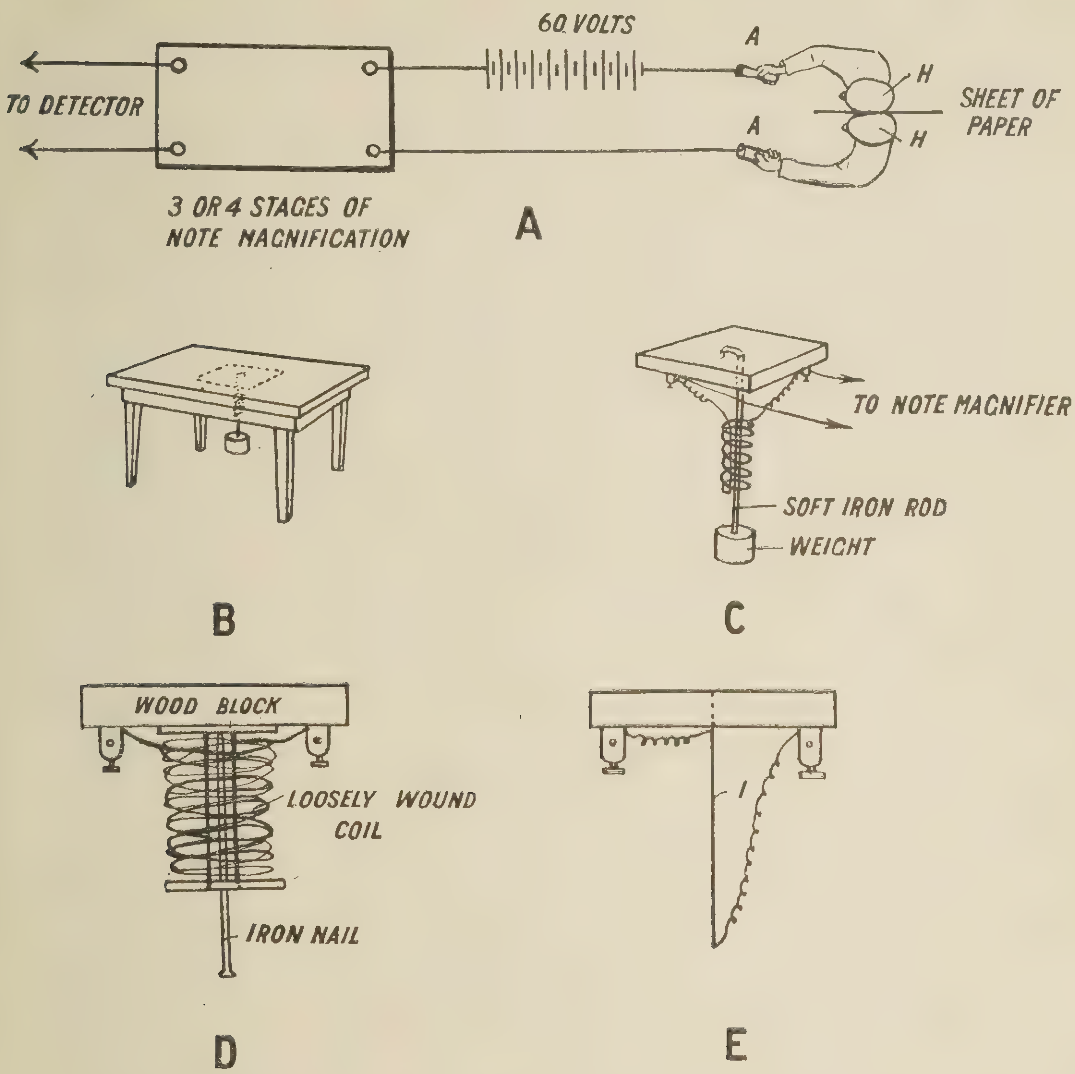

FIG. 19. Illustrating Some Unusual Methods of Telephonic Reception.

SOME UNUSUAL METHODS OF TELEPHONIC RECEPTION.—In a lecture to the Wireless Society of London in 1922 (349), the **Author** showed the following methods of rendering wireless telephony and signals audible.

Fig. 19a shows two metal handles AA, similar to those employed for electro-medical purposes, which are connected to the output transformer of a 4-valve note magnifier, and a 60-volt battery is connected in one lead as shown. If two persons now hold one handle each and place a sheet of thin paper between their heads as indicated they will both be able to hear speech or signals quite clearly.

One person alone can hear in the following manner. Both people hold handles as before, but one of the experimenters now holds the palm of his free hand against the ear of the

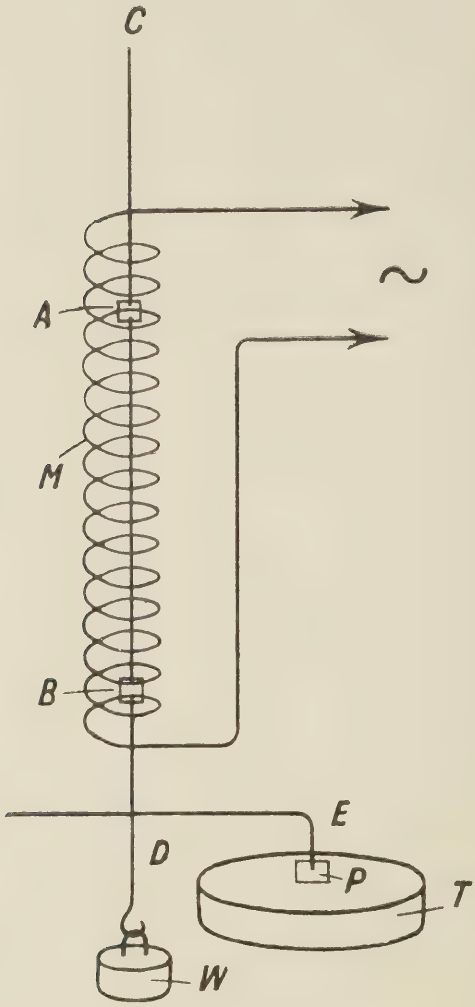

FIG. 20. Illustrating the Principle of Magnetostrication.

listener, with the sheet of thin paper between his hand and the ear. The action is doubtless electro-static.

Fig. 19b is a method of reception employing **Adler's** telephone, shown more clearly in Fig. 19c. A light weight is suspended on a short length of soft iron wire below the top of a table. This wire serves as the iron core to a loosely fitting bobbin of insulated wire wound to the same resistance as that of the secondary of a note magnifier transformer.

When signals pass through the wire slight changes of

length take place in the iron, due to magnetostrication, and any number of people can hear the signals if they place their heads flat against the table and listen with one ear.*

The Author also demonstrated the weak reproduction of signals by means of a loosely wound bobbin with a soft iron core. One end of the former was firmly attached to a block of wood which was held against the listener's ear, as shown in Fig. 19d.

Yet another method is shown in Fig. 19e. I represents a short length of soft iron wire attached to a block of wood at one end, and, connected as shown, it is possible to hear very strong signals even with this simple arrangement.

A magnetic phenomenon has been described by **F. Harrison Glew** (33) which may possibly have "Wireless" applications. Chrome-cobalt steels exhibit a great resistance against reversal of magnetic polarity when once magnetized, and he has shown that if a short bar magnet $2\frac{1}{2}$ins. long by $\frac{3}{16}$ in. in diameter and weighing 12 grammes be placed in a little glass cage to restrict its movements longitudinally and laterally, and be held above the poles of a powerful electro or permanent magnet with the poles of like sign opposite to each other, it will rise up in its glass cage and remain floating in the magnetic field.

* **H. Nagaoka** (of Imperial University, Tokyo) demonstrated the phenomena of magnetostrication by means of capillary ripples in 1904 (353) in the following way: A length of iron, or preferably nickel, wire A B, Fig. 20, was suspended from a short length of copper wire C A, to which it was soldered. The iron wire was suspended vertically in the axis of a magnetizing coil M (which was longer than the iron wire), and to the lower end of B was soldered a second length of copper wire B D having a suitable weight W at its lower extremity. Another wire D E was soldered at right-angles to D B, the end E was bent downwards and ended in a small plate P, which dipped into the centre of a circular or rectangular trough of mercury T.

By passing an alternating or intermittent current through M, capillary ripples were formed. These were projected on to the ceiling by placing a glass plate inclined at an angle of 45 degrees over the trough and illuminating the latter by a beam of light.

CHAPTER III.

The First Attempts at Wireless Communication

IN the year 1872 (four years after the introduction of the high bicycle) an American dentist named **Mahlon Loomis** took out a patent. He spoke of his discovery as a means of turning natural electricity to account for " establishing an electrical current for telegraphic or other purposes without the aid of wires, batteries, or cables" (4a), and he hoped by this method to telegraph from one continent to another.

He ran up two kites on adjacent mountain tops, using wires instead of string, and succeeded in signalling from one to the other by discharging electricity collected from the atmosphere to earth at the transmitter. Nothing further seems to have come of this scheme, although it is interesting to note that Loomis was, in all probability, the first to employ elevated vertical conductors or antennae for the transmission of signals to a distance.

Child's Experiments.—A somewhat similar experiment was carried out in 1909 by **Maurice Child.** At this date he was engaged on some experiments with a Hydro-electric Machine as a source of high-tension supply for Wireless Telegraphy. One day, during a very heavy hailstorm (his static machine being out of action at the time), he used the induced static charge on the aerial produced by the proximity of a dense thunder cloud overhead, and succeeded by its aid in signalling from Godmanstone to Charminster, a distance of three miles.

The cloud raised the potential of the aerial (which was 180 feet high) to some 25,000 volts, for a period of five or six minutes. In subsequent experiments with the same length of spark gap between aerial and earth, but using his hydro-electric machine as the source of high-tension supply, he signalled from Godmanstone to Jersey, the receiving station being the G.W.R. steamer " Roebuck," equipped with an electrolytic detector of his own design. He therefore concluded that, had the atmospheric electricity been available when he was on the steamer at Jersey, the clouds would have supplied sufficient energy to signal over the 100 miles separating the stations.

Fig. 21 shows the very ingenious high-tension key used by Child in these experiments, and invented by him a year previously for use when signalling with the hydro-electric

machine. A main spark gap was connected between the aerial and earth, and across this main gap he arranged a circuit consisting of a Morse key having its contacts submerged in oil, a tank containing distilled water, and a small auxiliary spark gap.

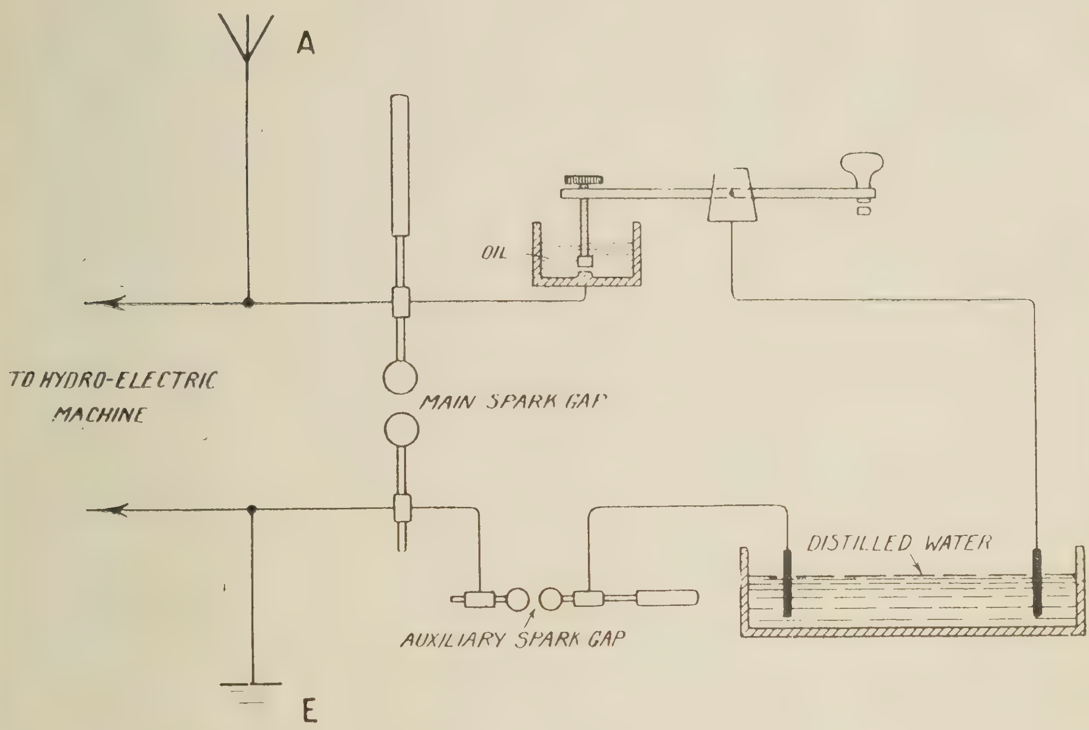

FIG. 21. M. Child's High-tension Key.

As long as the contacts of the key are closed a steady leakage of electricity takes place from the aerial through the water and across the auxiliary gap to earth. (The sparks seen at the latter are red in appearance and of a non-oscillatory character.) This leakage keeps the potential of the aerial from rising to a voltage sufficient to overcome the resistance of the main spark gap. When, however, the key is depressed the oil insulation stops the leakage, and the voltage instantly rises until the aerial discharges across the main spark gap.

EARTH CURRENT SIGNALLING.—In 1880 **Professor John Trowbridge** (4a, 4b and 4d) read a paper entitled "The Earth as a Conductor of Electricity" before the American Academy of Arts and Sciences, in which he gave the results of researches he had carried out in the detection of earth currents by means of a telephone.

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The Observatory at Harvard used to transmit time signals along a line wire to a distance of about four miles, using an earth return, and he was able to pick up these signals at a distance of a mile from the observatory and well out of the direction of the line wire. His receiver was a telephone, which he connected between the gas pipes in one building and the water pipes of another only 50 feet distant.

Trowbridge carried out many other experiments of a similar nature, one of his suggestions being a method of wireless communication between ships by means of earth leakages. Another of his proposals was the employment of an electro-magnetic induction method for communication between ships, which is of particular interest as it may be described as the forerunner of direction finding between ships at sea. His suggestion was that a wire might be stretched between the yardarms of a steamer's foremast, and connected at its ends either with a powerful battery fitted with an interrupter when used for transmission or across the terminals of a telephone if used for reception.

If one of the ships is listening while the other is transmitting, when they are within range of one another and the coils of wire on the two ships are parallel, the interrupted currents will be heard by the receiving ship. If one of the ships, however, is turned round so as to place its coils at right-angles to those on the other vessel, as it turns the signals will gradually get weaker until no sounds are heard.

If, therefore, the coils of the receiving ship be movable, the listener can quickly find the direction of the transmitting ship. Trowbridge realised that this method was impracticable owing to the limitation of range. He computed that in order to signal half a mile a coil of ten turns would require a radius of 800 feet.

Between 1882 and 1900 **Sir William Preece** (4a), (4b), (9), Engineer-in-Chief of the British Post Office, conducted a very thorough investigation of wireless telegraphy. His experiments included signalling by earth currents or leakages, on the lines of Morse, Lindsay, and others, by electro-static induction, and also by electro-magnetic induction. His greatest successes took place in the Bristol Channel, where he successfully telegraphed from Lavernock Point near Cardiff, to the island of Flatholm, 3·3 miles distant, by means of a system in which he made use of both induced and leakage currents. For some years telegraphic communication was

maintained by this system, "Evershed" relays being added to actuate a call bell. Communication was also established between Rathlin Island and the Irish coast, a distance of four miles.

In 1894 **Enrich Rathenau** (4a), (4b), of Berlin, with the assistance of **Rubens** and **W. Rathenau**, repeated the experiments of Preece, Stevenson, and others, and succeeded about equally well, the distance they achieved being three miles on the Wannsee Lake, near Potsdam. An account of their work, abstracted from the "Elektro-Technische Zeitschrift" of Berlin, appeared in the "Scientific American Supplement" of January 26th, 1895.

In 1887 **Willoughby Smith** (4a) suggested a method whereby communication might be maintained between Crookhaven in Ireland and the Fastnet Rock Lighthouse by employing leakage currents. This lighthouse is situated off the extreme S.W. corner of Ireland, in a very exposed position; consequently, every time a submarine cable was laid it was quickly chafed against the rocks by the rough seas and broken.

On the recommendation of the Royal Commission for Lighthouse and Lightship communication, Willoughby Smith's plan was adopted in 1896, and worked satisfactorily for several years. His method was very similar to that of Morse, Lindsay, and others, the main difference being that instead of the cables joining the earth plates being arranged parallel to one another he placed them in line. He led a cable from Crookhaven to within 100 feet of the Fastnet Rock, and connected the end of it to a metal anchor, and on the rock he arranged a cable, connected to submerged plates, from one side of the island to the other, in line with the Crookhaven cable, the receiving instruments being operated by means of the current due to the difference of potential between the two ends of the cable across the rock.

TELEGRAPHIC COMMUNICATION BETWEEN TRAINS IN MOTION (4a), (4b), (1070).—**A. C. Brown**, in 1881, suggested the possibility of communicating with moving trains by electromagnetic induction, for which purpose he suggested the winding of a coil of wire round the engine (see letter in the "Electrician" of March 21st, 1885).

In 1883 **Willoughby Smith**, in a paper before the Institution of Electrical Engineers, also proposed a system based on the principle of electro-magnetic induction, his idea being to have

a series of spirals at intervals along the railway track, under the train, and a fixed spiral attached beneath the train itself.

In 1885 **Edison,** working in conjunction with **Gilliland,** invented a very ingenious system, which was patented in England on June 22nd, 1885, in their joint names.

They made use of existing telegraph lines running parallel with the track, and by aid of static induction were able to signal along them to and from moving trains, simultaneously with the ordinary messages which the telegraph lines were conveying across the country, without interfering with them in any way, and without interference from them.

This, though totally different in principle, may be considered as the forerunner of the "Wired Wireless" employed in England for the first time on November 3rd, 1922,* when the Lord Mayor of Bristol spoke from Bristol over the ordinary trunk telephone lines between London and Bristol, ordinary telephonic conversation being carried on along the same lines all the while, without any mutual interference. His speech arrived quite unimpaired at Marconi House, and was broadcast thence far and wide.

The method employed was very different from that of Edison, which was but the germ of the idea. The former was a species of inductive signalling, while the latter was achieved through the medium of high-frequency carrier currents.

Edison's arrangement is illustrated in Fig. 22. The apparatus employed is so arranged that it is automatically either a transmitter or a receiver, according to the position of the key. T represents the existing telegraph wires conveying the ordinary telegraphic traffic. One fixed station is arranged at a convenient point by the side of the railway track. The instruments there are connected by a wire A to a cylinder of metal C, surrounding a short length of the telegraph lines but well insulated from them and from earth. Alternatively a number of condensers may be used, as shown on the top left-hand side of the diagram.

Line A is connected to an Edison electro-motograph, already described in Chapter II., Fig. 10. The chalk cylinder of the electro-motograph is connected through the switch F to earth at E, or to the railway lines. This completes the receiving circuit. The transmitter consists of a small induction coil, the secondary S of which is connected to earth at E, and

* Wired wireless had already been in use in America and Germany for several years.

to the condenser cylinder C, through the electro-motograph, the switch F being left open during transmissions. The primary of the coil N is connected in series with a battery B and interrupter I, across which is arranged a short circuiting key K, which normally keeps the interrupter out of action.

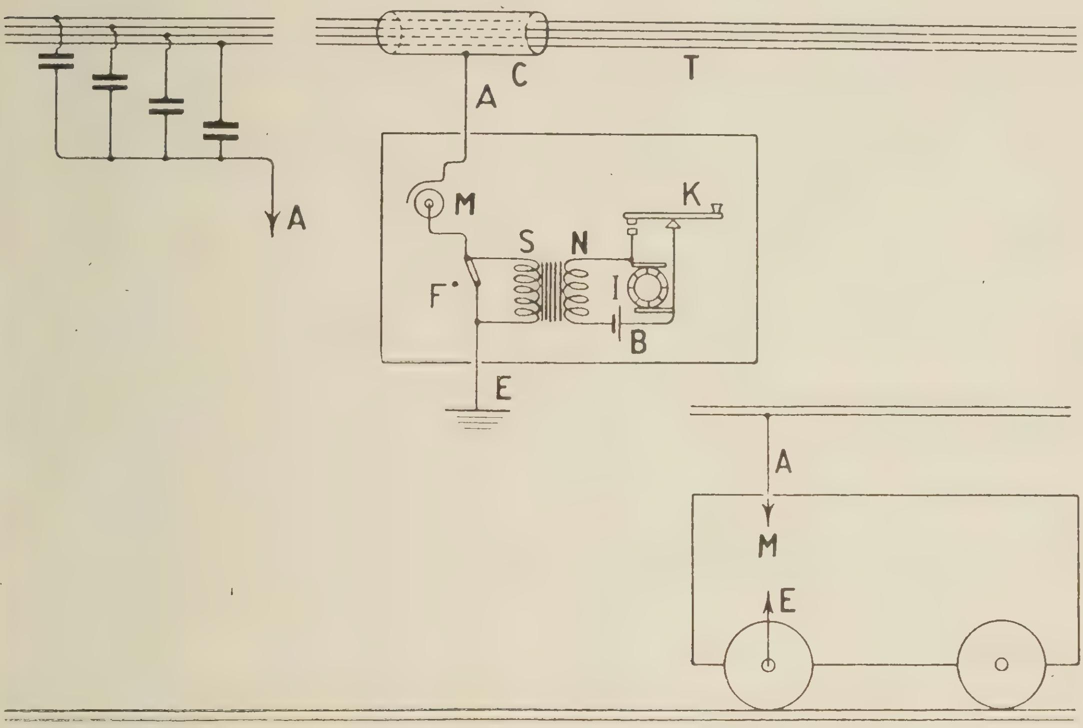


FIG. 22. Illustrating Edison's method of communicating with trains.

This simple apparatus completes the land station. Exactly similar instruments are fitted in one of the carriages on the train, earth connection being made in this case to the wheels of the carriages and the "motograph" being connected either to a long strip of metal fitted right along the train or to the metal roof thereof, and although 20 or 30 feet often separated the carriage from the telegraph wires it was found that quite good signals could be transmitted from one set of instruments to the other by electro-static induction.* This system was first put into operation at Staten Island, U.S.A., and in 1887 on the Chicago, Milwaukee, and St. Paul line and on the Lehigh

* RADIO COMMUNICATION WITH EXPRESS TRAINS (1070).—In 1924 the Radio Society of Great Britain, represented by **P. R. Coursey, M. Child,** and **L. McMichael,** carried out tests in conjunction with the L.N.E. Railway to investigate the possibilities of two-way radio communication with moving trains.

A wave-length of 185 metres was employed, and ranges of 100 miles were easily obtained, the transmissions from the train being heard at a distance of 270 miles. The screening effects of tunnels and steel girders in the roofs of stations were specially noted.

Valley Railway. It proved a complete success, so far as working was concerned ; but, unfortunately, no one made use of it and it was discontinued.

In 1887 **Oliver Heaviside**, by an induction method, succeeded in carrying out telephonic communication from a gallery in the Broomhill Colliery, 350 feet deep, where he arranged a circuit over two miles in length. Speech was received on a land line above ground running approximately parallel with this.

In 1892 **Charles A. Stevenson** signalled from the mainland to the North Unst Lighthouse, on the island of Muckle Flugga, by an induction method. He arranged a huge coil of wire, which was wound five times right round the island on telegraph poles, his signals being received on the mainland, half a mile distant, on a similar coil of wire, also on telegraph poles.

HUGHES' INVESTIGATIONS.—**D. E. Hughes** was originally a professor of music, but prior to the invention of his microphone he had already made himself famous in the electrical world by the invention of his typewriting telegraph in 1859 (4). Many of these instruments are still in use, and, as we shall see later, have been employed by the Post Office for radiotelegraphy.

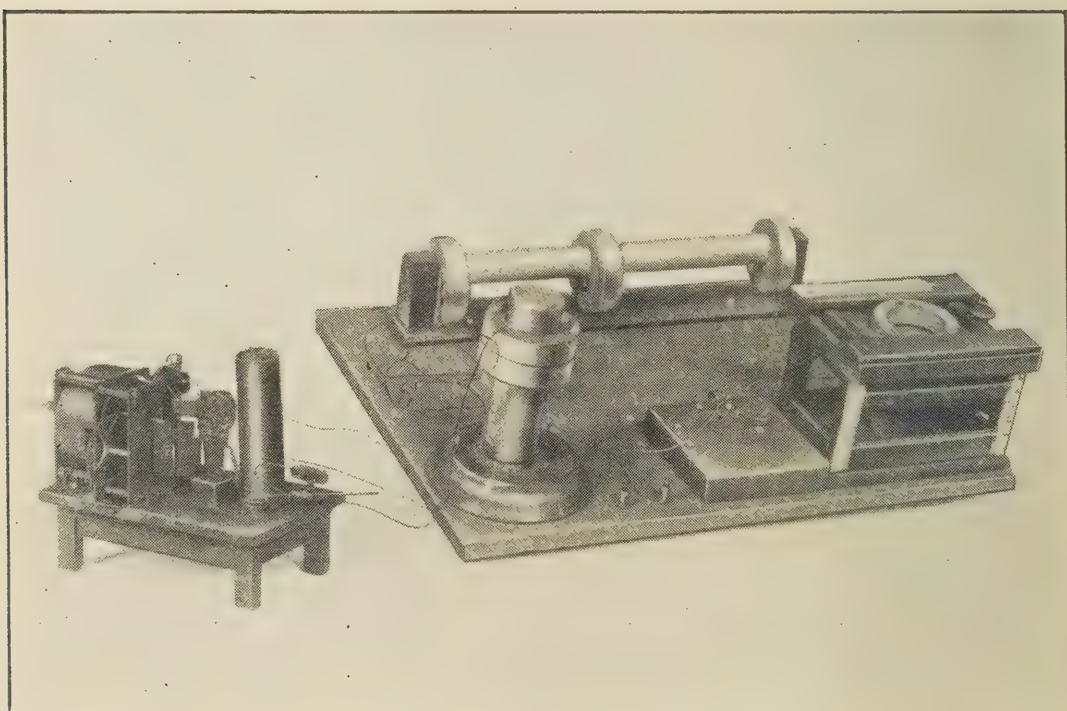


FIG. 23. Hughes' Induction Balance.

Unfortunately, none of Hughes' investigations was published until 1899, although he gave several private demonstrations.

In 1879 he showed his results to several members of the Royal Society—Sir William Crookes, Sir Robert Austen, Sir William Preece, and Professor Adams. Again, in February 1880, he gave a similar demonstration to Mr. Spottiswoode (then President of the Royal Society), to Professor Huxley, and to Sir Geo. Stokes.

Mr. Campbell Swinton gave a very interesting account of the work of Hughes in the Proceedings of the Commemoration Meeting of the Institution of Electrical Engineers, February 1922, from which I quote the following note, made by Hughes in his notebook at the time, and having reference to the 1880 demonstration. (The notebook, and several others, are now in the keeping of the Science Museum authorities at South Kensington) :

"February 20th, 1880.—Mr. Spottiswoode, President of the Royal Society, Professor Stokes, and Professor Huxley visited me to-day at half-past 3 p.m., and remained until quarter to 6 p.m. in order to witness my experiments with the extra current thermopile, etc. The experiments were quite successful, and at first they were astonished at the results ; but at 5 p.m. Professor Stokes commenced maintaining that the results were not due to conduction but induction, and that results were then not so remarkable as we could imagine rapid changes of electric tension by induction. Although I showed several experiments which pointed conclusively to its being conduction, he would not listen, but rather pooh-poohed all results from that moment. This unpleasant discussion was then kept up by him, the others following his suit, until they hardly paid any attention to the experiments, even to the one working through gas pipes in Portland Street to Langham Place on roof. They did not sincerely compliment me at the end on results, seeming all to be very much displeased because I would not give at once my thermopile to the Royal Society so that others could make their results. I told them that when Professor Hughes made an Instrument of Research it was Professor Hughes' researches, and no one else's. They left very coldly, and with none of the enthusiasm with which they commenced the experiments. I am sorry at these results of so much labour, but cannot help it.

"(Signed) D. E. HUGHES."

One can understand and sympathise with Professor Hughes' very natural feeling of disappointment, and it is pleasing to find that the very gentlemen who then appeared to belittle his work became, in the same year, his firm supporters, as is borne out by the fact that on June 7th following he was made a Fellow of the Royal Society, Mr. Spottiswoode being president, and Professors Stokes and Huxley the two secretaries and members of the Council.

Eight years later, in 1888, Professor Hughes, now an F.R.S., gave a further demonstration to Professor Dewar and Mr. Lennox. We can therefore accept his work as being fully authenticated although unpublished. Briefly, the following were his discoveries :

When engaged on some work with an induction balance he noticed some peculiarities in the behaviour of a loose contact in the circuit. This caused him to carry out a series of experiments with loose contacts, and he discovered that on the

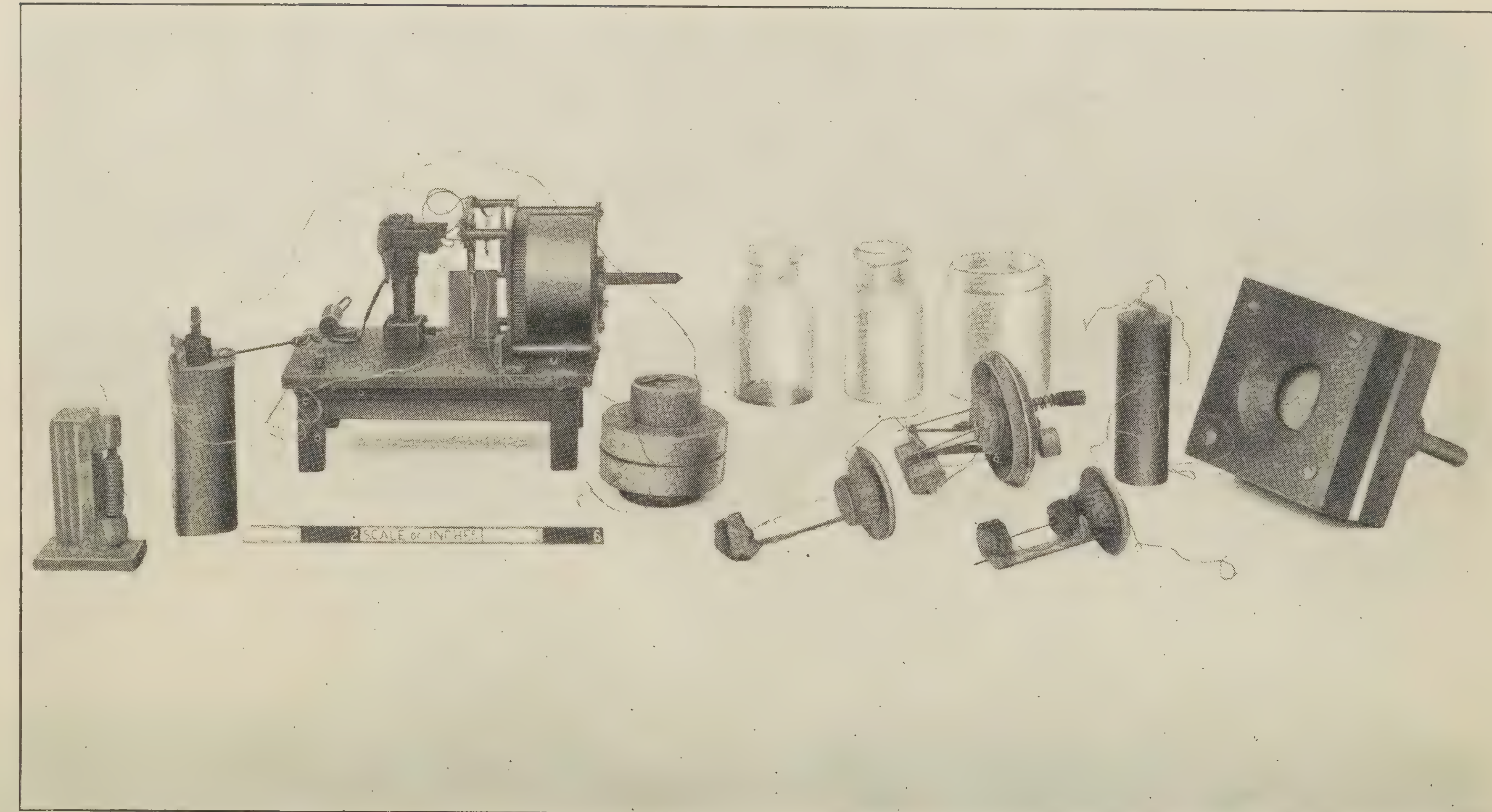


FIG. 24. Group of apparatus used by Hughes for wireless signalling, now in the Science Museum, South Kensington. (From the left) A microphone, a battery connected to Hughes' interrupter and coil from induction balance, three microphonic detectors in front of the glass jars in which he mounted them, a battery, and a home-made telephone. (*By kind permission of the Exhibition Authorities*)

sudden interruption of a current in any coil the " extra " current,* at break, caused the emission of " invisible electric waves " which became evident if a microphonic joint were used as a receiver with a telephone, and he showed that these waves penetrated solid walls and apparently travelled to great distances. He transmitted signals in this manner to a distance of about 60 feet, and on several occasions walked up and down Great Portland Street, London, with the telephone to his ear and heard them at a distance of 500 yards. He also noticed that the waves appeared to be reflected from some of the buildings.

Fig. 23 illustrates Hughes' Induction Balance, while Fig. 24 is a group of historical apparatus (62) used in these experiments. On the left-hand side is seen the transmitting apparatus. Towards the right-hand side of the photograph are several types of microphone invented by Hughes. These were really the forerunners of the self-restoring coherers used by Tommasina, Solari, Marconi, Lodge, and others at a later period.

Hughes' Microphonic Detectors.—At first he connected a telephone receiver across a microphonic contact of carbon and steel, using no additional E.M.F. in the receiving circuit ; but later he included a small voltaic cell in series with the microphonic contact and the phones.

Having noticed the effect of an " extra current " spark in the vicinity of a microphonic contact in the circuit of his induction balance, Professor Hughes continued his investigation along the following lines : He connected his transmitter (62), consisting of a coil of wire C, battery B, and interrupter I, by a wire W to a microphonic contact M in circuit with a telephone T, as represented in Fig. 25, and found that he could always hear the " extra spark " of the transmitter in the phone.

He tried various substances as contacts at the interrupter, and found that metal to metal produced a better effect than carbon to carbon or carbon to metal. He placed an iron core in the coil, and found that although it gave a greater visible sparking effect it diminished the strength of the received sounds in the telephone.

He also experimented with the Faraday electro-magnet at the Royal Institution, excited by a powerful battery, obtaining

* The author carried out some experimental transmissions, using the extra current spark at the contact of an electric bell to energise an aerial, and succeeded in signalling one mile by this means in 1907 (see ref. (22)).

very poor results. He therefore came to the conclusion that his microphone was influenced by the " extra spark " solely, and not by electro-magnetic induction. He used coils in transmitting and receiving circuits, placing them in the same plane and at right-angles, without affecting his results ; he reduced the number of turns of wire, and even used a battery and interrupter only, without any coil, and heard the sounds as distinctly as before.

He experimented with various forms of microphonic contact, probably his most sensitive one being that which consists of a steel hook in contact with a loop of fine copper wire, previously oxidised and well smoked in the flame of a spirit lamp. These he placed in a small bottle for safety. Fig. 26 is a photograph of three such receiving instruments.

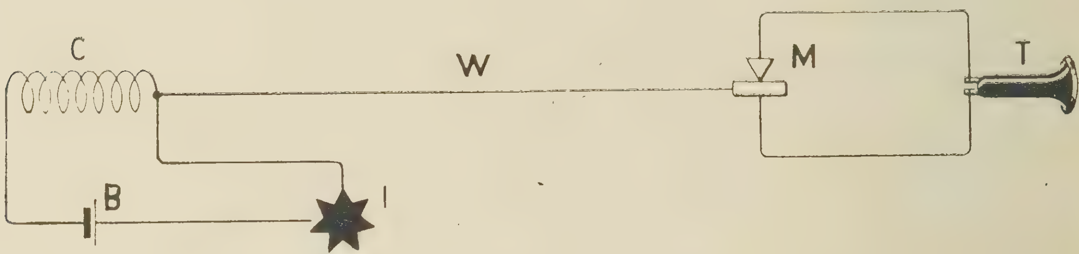


FIG. 25. Hughes' Transmitter and Microphonic Detector.

(Hughes was not the first to make use of soot in the manufacture of a microphone—**Edison** invented a microphone, using a button of compressed soot between a diaphragm and a rigid metal backing, for telephony, which he patented in the United States in 1878 (this is described in " Fifty Years of Electricity," by Fleming)—but he was the first to employ it for the purposes of his experiments to detect the then unknown Hertzian waves.)

Another form of microphone which he tested was a tube containing filings between two carbon plugs (see Fig. 27), but finding that the filings continually stuck together (or, as we should now say, cohered) and made the microphone very unreliable, he discarded it without having realised the importance of the phenomenon. Had he been a little more observant, remembering the other facts he had discovered, he could, in this little tube, have forestalled the **Branly** tube and **Marconi** coherer; but the opportunity was lost, and the credit of the early types of filings coherers is due to the work of Branly and Marconi.

Strangely enough, he also tested contacts of iron and mercury, which he found sensitive but troublesome. Thus he also unknowingly got near to the discovery of the **Costelli** and **Solari** detectors mentioned later in this work. He discovered that a microphonic contact used in conjunction with a telephone was more sensitive to a small charge of electricity than a gold leaf electroscope, and in October 1879 he made the most important discovery that the wire, as shown at W in Fig. 25, could be discarded, and that his transmitter would influence his receiver at a distance. He had discovered the elements of radio transmission and reception.

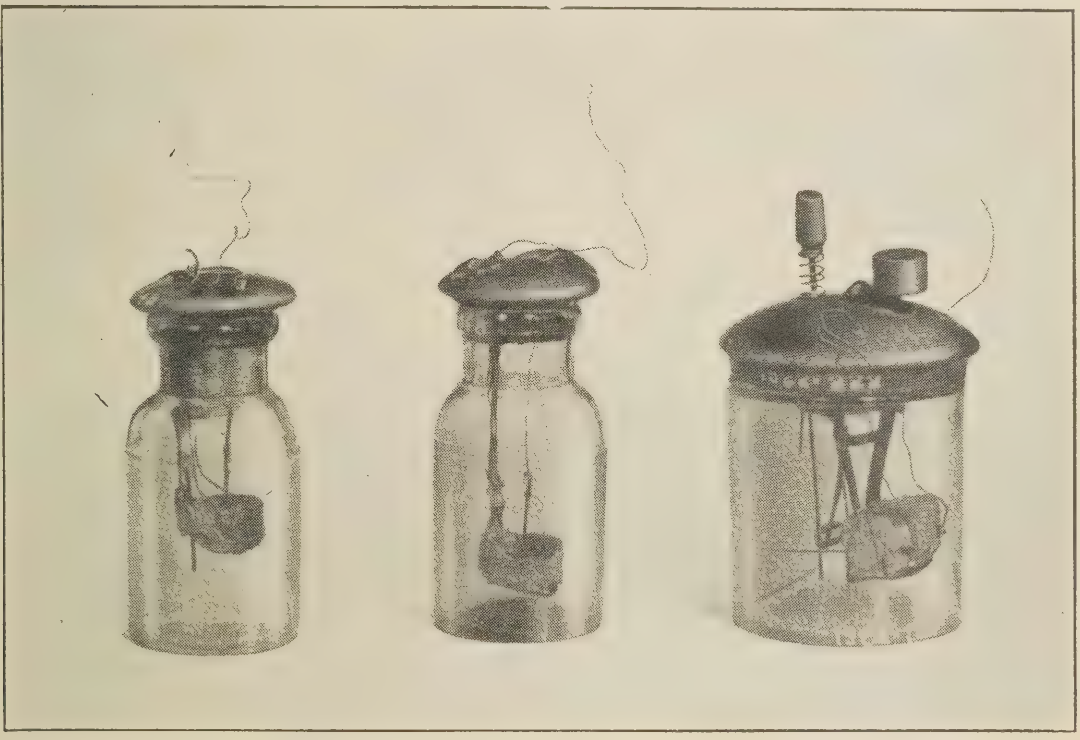


FIG. 26. Three receiving instruments devised by Hughes, which utilise various forms of microphonic contact.

In November of the same year he connected a fender to his interrupter, as he said (in his notebook), to act as a "radiator," and later he used a couple of short lengths of wire, one on each side of his "extra spark," and a similar couple of wires, one on each side of his microphone. These were very similar to the arrangements used by **Hertz**. He also found that he could obtain greatly increased results by the employment of earth connections to the transmitter and receiver.

The following statement appeared in the "Globe" of

May 12th, 1899: "Hughes' experiments of 1879 were virtually a discovery of Hertzian waves before Hertz, of the Coherer before Branly, and of Wireless Telegraphy before Marconi and others." Hughes conducted these experiments nine years before the discoveries of Hertz, and seventeen years before the advent of Marconi.

The notebooks and early apparatus of Professor Hughes are now at the Science Museum at South Kensington. An interesting account of this apparatus by Mr. Campbell Swinton appears in "Nature" for April 15th, 1922.

Hughes had previously invented the microphone in the year 1878, at which date the result of his researches thereon was communicated to the Royal Society of London and aroused great interest.

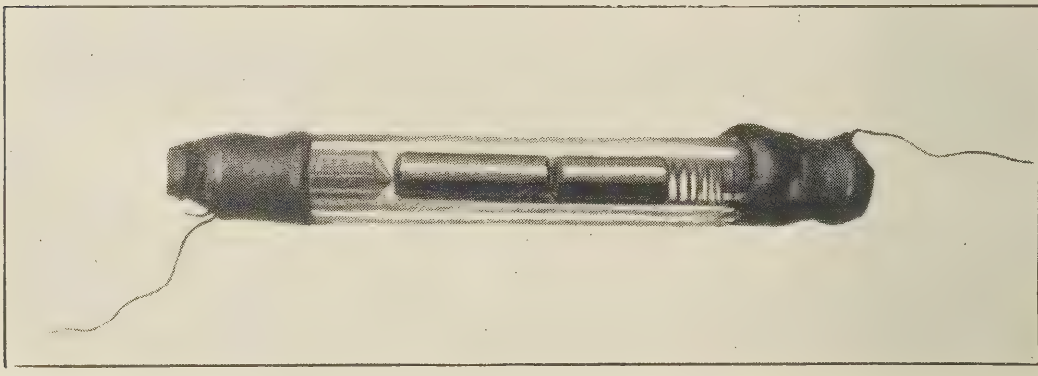


FIG. 27. One form of carbon microphone employed by Hughes which strongly resembles a coherer.

In improved form, Hughes' microphone still plays a most important part in telephony and radio-telephony. It has already been mentioned that in the same year **Edison** patented a telephone transmitter in U.S.A., in which a microphone with compressed lampblack was employed, and Hughes' experiments aroused a vigorous controversy with Mr. Edison, who claimed that his ideas had been appropriated.

Hughes showed that the slightest sound was greatly magnified by his microphones. One of his favourite experiments at this time was to place a house fly in an empty match box near to the microphone. It was said that the sound of the fly's footsteps walking in the box, heard in the telephone resembled that of the tread of an elephant in a primeval forest.

The actual match box used by Hughes for this purpose is shown in Fig. 28, which also shows an early form of microphone using three iron nails.

The type-printing telegraph (Fig. 29) invented by Hughes was referred to at the commencement of this chapter. This machine was, in 1923, employed for some time for radio-transmission by the Post Office (21) on a duplex system working between London and Berlin, handling 25 messages per hour in each direction. "The one route is from G.P.O. by land wire to Stonehaven, and thence by wireless to Zellendorf, and the other route is direct from Königswusterhausen to an aerial on the roof of the G.P.O. in London, and the results so far obtained are most satisfactory." How pleased Professor Hughes would be could he see the advances that have been made since his time and find his own type-printing telegraph (which has been in constant use on land lines for many years) now being turned to account for radio-telegraphy !

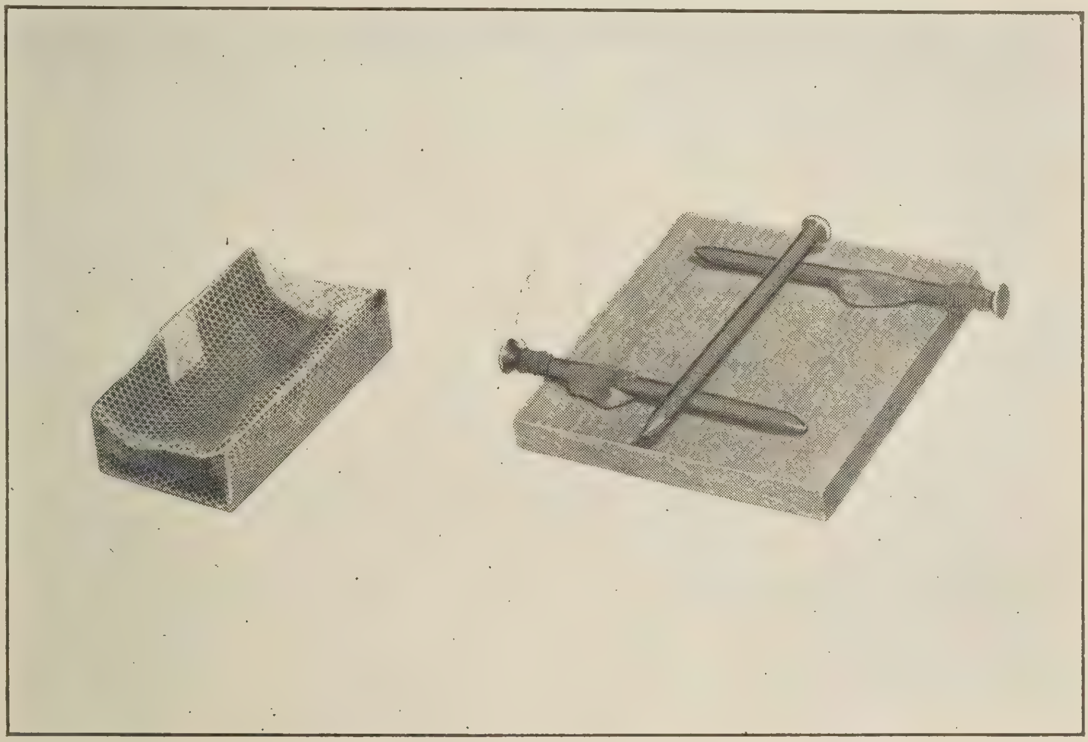


FIG. 28. The actual match box used by Hughes in demonstrating the sensitiveness of his microphone is shown here, together with his early type of microphone composed of three nails in light contact.

While there is no doubt that, working entirely by himself, with the crudest of home-made apparatus, often fastened together only with sealing wax and twisted wires, Hughes made all the discoveries before described, other workers in various parts of the world had already noticed some of the phenomena concerned, but none of them had carried their investigations to a conclusion.

Henry's Researches.—In 1842 **Professor Joseph Henry,** of Princeton, U.S.A. (23), made a communication to the Smithsonian Institution in Washington. I requote his words from a paragraph in a lecture delivered by **Sir Oliver Lodge** at the Finsbury Technical College, February 1st, 1923, from which it will be seen that he evidently had an intuition of the far-reaching possibilities of his observation; he says: "It would

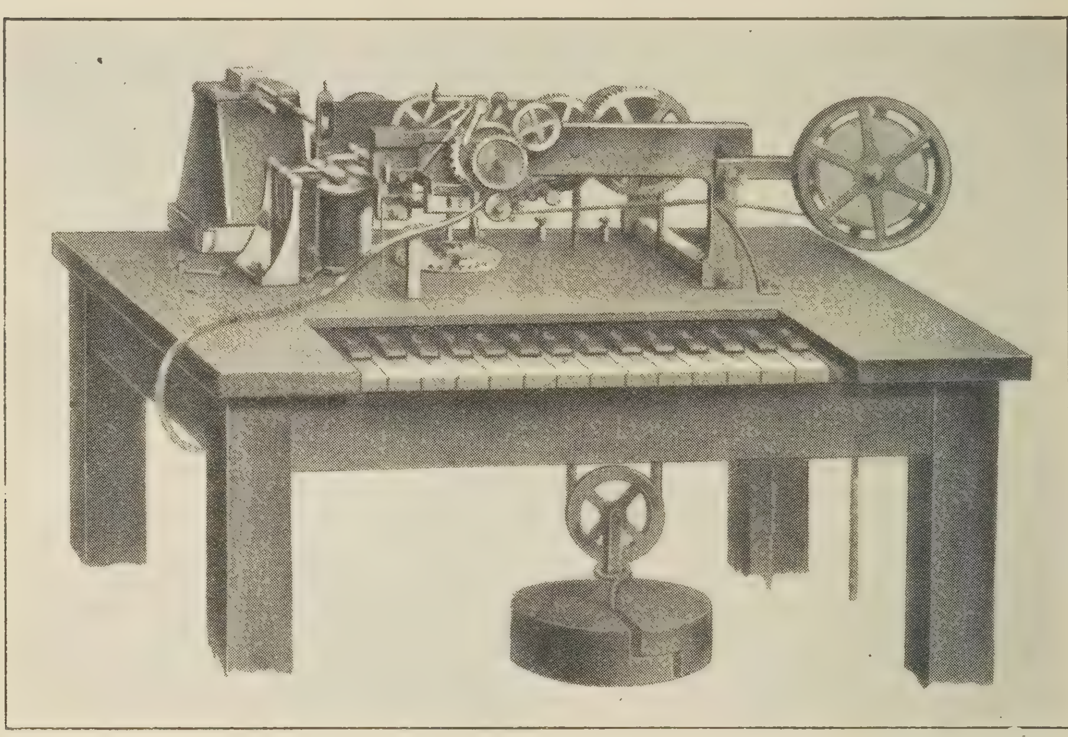


Fig. 29. Hughes' Type-printing Telegraph.

appear that a single spark is sufficient to disturb perceptibly the electricity of space throughout at least a cube of 400,000 feet of capacity,* and it may be further inferred that the diffusion of motion in this case is almost comparable with that of a spark from flint and steel in the case of light." "That is to say," says Lodge, "so early as 1842 Joseph Henry had the genius to surmise that there was some similarity between the ethereal disturbance caused by the discharge of a conductor and the light emitted from an ordinary high temperature source." We now know that both sources emit ether waves, though they differ prodigiously in length. In the same year

* From "Polytechnic Review," March 25th, 1843.—"Professor Henry communicated to the American Society that he had succeeded in magnetising needles by the secondary current in a wire more than 200ft. distant from the wire through which the primary current excited by the single spark from an electric machine was passing.

"He observed several effects which we now know are due to Hertzian waves, but he naturally thought them due to induction."

(1842) Professor Henry drew attention to the oscillatory character of the discharge of a Leyden Jar (27).

In 1875 **Edison** also observed the possibility of drawing sparks from insulated objects in the neighbourhood of an electrical discharge, but he did not pursue the matter, describing the phenomenon as "electric force."

In June 1876 **Sylvanus P. Thompson** gave a demonstration of this phenomenon to the Physical Society, but he wrongly ascribed it to then well-known principles.

DOLBEAR'S SYSTEM OF WIRELESS TELEGRAPHY.—**Professor A. E. Dolbear** (4a), (93), of Tuft's College, Boston, applied for a U.S. patent in 1882 for a system of wireless telegraphy. He described his system and experiments before the American Association for the Advancement of Science in 1887.

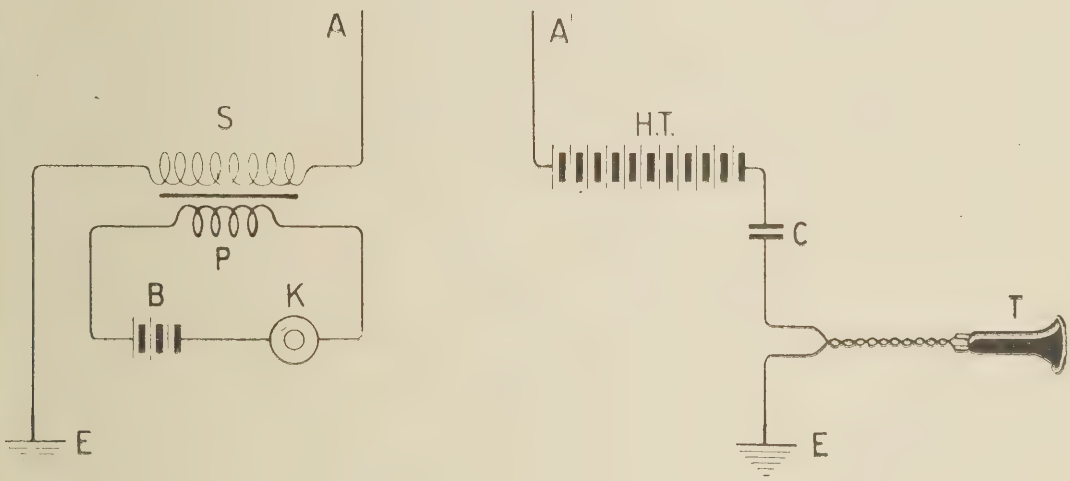


FIG. 30. The transmitting and receiving apparatus used by Dolbear in 1882.

Fig. 30 shows the apparatus and connections which he employed. His idea apparently was to charge the earth in the vicinity of the receiving station to a negative potential of about one hundred volts by means of a high-tension battery H.T., one terminal of which he connected through a telephone T to earth at E. By connecting the secondary of a coil S to earth at the transmitting station he thought he created fluctuating changes of positive potential in the earth, when words were spoken in the proximity of a microphone K in the primary circuit.

These potential changes would, he thought, cause corresponding changes of potential at the receiving station and be heard in the telephone.

At first he connected the free terminal of his induction coil at the transmitter, and the free terminal of the high-tension battery at the receiver, to large condensers ; but he afterwards obtained vastly better results by replacing the condensers by aerials attached to gilded kites. Dolbear's explanation, as stated above, is not very clear, but in the light of more modern knowledge it seems probable that the results he obtained were due to electro-static action, as of course the earth's potential would remain constant, and the potential changes would take place in the aerial system.

During his first experiments he employed a Morse key for transmission in place of the microphone. For some other experiments he employed an electro-magnetic telephone, but he more often used the electro-static telephone of his own invention, already described in Chapter II. By means of this simple system he succeeded in telephoning a distance of half a mile, and in the Supplement of the " Scientific American " for December 6th, 1884, it is stated that Dolbear succeeded in signalling a distance of 13 miles. He suggested the employment of his system for communication between ships at sea.

In a later chapter of this book a comparative diagram will be found, which shows how extremely near he came with his electro-static system to the success achieved by Marconi. Unfortunately for him, at the time he was engaged on his researches, Hertz had not given to the world the results of his epoch-making discoveries of the production and detection of electro-magnetic waves, and, of course, the Righi exciter was unknown.

CHAPTER IV.

The Discovery of Electro-Magnetic Waves

THOMSON'S EXPERIMENTS.—In 1875 **Professor Elihu Thomson** (98), while conducting a course of lectures at the Central High School, Philadelphia, discovered experimentally the long electro-magnetic waves first announced in the mathematical theory of **Clerk Maxwell** in 1864. **Professor Monroe B. Snyder,** writing in the "General Electric Review" of March 1920 (vol. XXIII., No. 3), gives some interesting details of the discovery.

It seems that he, Professor Snyder, was at work on the sixth floor of the Central High School building when Professor Thomson came bustling in, bent on testing whether the ether disturbance which he was exciting in the physical room on the first floor could be observed on the sixth floor. "Applying the sharpened point of a short lead pencil near the brass door knob of the observatory library door, Thomson called attention to the delicate sparks that were passing between the point and the door knob."

Thomson had already traced the ether disturbance in the lecture hall on the first floor at a distance of about 60 feet, on the third floor at a distance of about 80 feet, and now, at the door knob on the sixth floor, a distance of about 100 feet. "It is interesting," says Professor Snyder, "to know what odd electric radiating system was at the time kept in action in the physics room. In an effort to magnify the electrical oscillations then being studied for another purpose Thomson had connected one terminal of the induction coil to the water pipe, and the other to a large metallic still, which stood at hand, and which he duly insulated by placing it on a glass jar. Vigorous sparks of a few inches were then passed, and the unique radiating system produced results that soon induced the professor to widen the area of his observations in the manner mentioned."

"The invisible long electro-magnetic waves were thus definitely and repeatedly traced by Professor Elihu Thomson in 1875 to the distances and effects stated, and through five intervening floors, by a means much simpler than the detector of **Hertz,** and yet 12 years prior to Hertz's celebrated verification of the Maxwell theory."

The pursuance of other studies appears to have diverted Professor Thomson from the further examination of these ether waves, so that what would have been an epoch-making discovery remained in obscurity, and it was left to Hertz to rediscover them; and through his brilliant researches and untiring investigation of their properties his name has justly been associated with them and so handed down to posterity.

MAXWELL'S PREDICTIONS.—As far back as 1864, **Clerk Maxwell,** in his paper on "The dynamical theory of the electro-magnetic field," assuming the existence of the ether,* deduced mathematically the existence of electro-magnetic waves therein.

Sir Oliver Lodge, in the Sylvanus P. Thompson Memorial Lecture, delivered at the Finsbury Technical College, February 1st, 1923, summarised the work of Maxwell as follows:

(1) Maxwell said that if electric waves could ever be generated they would travel at the velocity of light.

(2) That light was essentially an electro-magnetic and not a mechanical phenomenon.

(3) That the refractive index of a substance was intimately related to its di-electric co-efficient.

(4) That conductors of electricity must be opaque to light.

In the words of Lodge, "He showed that the ether had two great and characteristic constants of value utterly unknown to this day [1924], though guessed at by a few speculators like myself, one of them the electric constant of **Faraday,** called 'k,' and the other, the magnetic constant of **Kelvin,** called 'μ.' It was impossible then, and it is impossible now, though it is not likely always to remain impossible, to determine the value, or even the nature, of these constants; but he did perceive a way of measuring their product, and he was the first to measure it. Maxwell showed that it must be equal to the reciprocal of the square of the velocity of light."

For 24 years after Maxwell predicted the possibility of producing ether waves no proof of their existence or production was forthcoming.

In 1883, at the Southport meeting of the British Association,

* **Huygens,** a Dutch philosopher (27), in the 16th century, was the originator of the undulatory theory of light, which assumes that light is propagated by vibrations of an imponderable medium called the Ether.

Fitz-Gerald, who had already given several papers attempting to disprove the possibility of generating waves in the ether in accordance with Maxwell's theory, suggested that he considered it might after all be possible to produce them by utilising the oscillatory discharge of a Leyden Jar if only means could be found of detecting their presence. The oscillatory character of the sudden discharge of a Leyden Jar had already been deduced by **Von Helmholtz** in 1847, mathematically demonstrated by **Kelvin** in 1853, and proved experimentally by **Feddersen** in 1859.

Discovery of Waves on Wires.—In 1870 **Von Bezold** (103), (104), (28), discovered that electric impulses are reflected from the insulated end of a conductor, and he showed the presence of potential nodes and antinodes at different points on a wire.

At this time he was experimenting with "Lichtenberg" dust figures (31). A glass plate is covered on one side with a sheet of metal foil, connected to earth. If a conductor be placed in the centre of the side of the glass remote from the foil, and suddenly discharged, the upper surface of the glass becomes electrified. If now dust be sprinkled over it, it will form into different types of pattern, according to whether the discharge be negative or positive. These dust figures were the forerunners of "Spark Photographs," probably first taken by **J. Brown** ("Phil. Mag.," December 1888) (32).*

Fig. 31 shows the arrangement employed by Von Bezold when he discovered the production of potential nodes and antinodes, 18 years before Hertz published an account of his experiments on the propagation of electric waves along wires (Wiedemann "Ann." 34, page 551), and it will be seen that Von Bezold employed a spark-gap S, for the production of high-frequency oscillations. G represents a sheet of glass beneath which is a sheet of tin foil connected to earth at E. I is a choke coil, connected to earth and to one side of the spark-gap S, and also to a length of wire bent so as to form two loops L and L_1 (adjustable in size). The ends of the loops X, Y, and Z rest on the upper surface of the glass sheet G. By varying the loops L and L_1 the dust figures produced at Y could be caused to vanish, while those at X and Z became

* In the "Archives of Radiology and Electro-Therapy," February 1919, the **Author** gave an account of the work done in spark photography by various workers, and by means of spark analysis showed the cause of the contradictory results achieved by various electro-therapeutists in the treatment of patients by high-frequency currents, to be due to the predominance of positive or negative electricity.

strongly marked, showing a rise of potential at the ends of the loops L and L_1, and no potential between them at Y, indicating that the electrical impulses were reflected from the free end of the wire, producing potential nodes and antinodes along its length. Thus was established an experimental proof of Maxwell's theory of the propagation of electric disturbances, and the existence of a definite velocity of propagation (28).

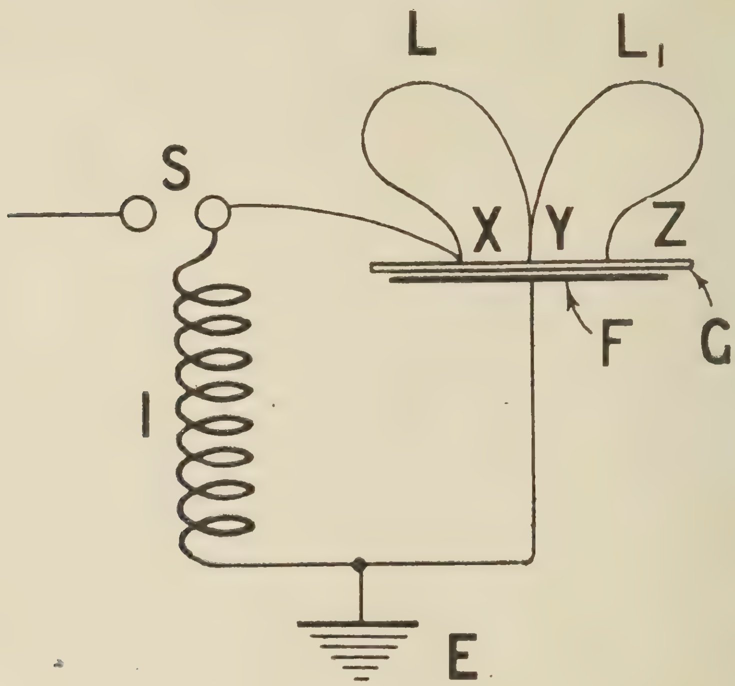


FIG. 31. The arrangement with which Von Bezold observed the production of voltage nodes and antinodes.

Von Bezold also showed that, given two paths to earth, as shown in Fig. 31, the discharge current from gap S (if the gap were small) split up, part of it taking one path and part the other.

LODGE'S EXPERIMENTS.—In 1887 and 1888 **Lodge** conducted a series of experiments on the oscillatory discharge of Leyden Jars, mainly in connection with the phenomena of lightning, and he showed that "waves" could be produced and detected, and that their wavelengths could be measured, by causing them to travel along guiding wires, adjusted to correct lengths for "sympathetic resonance." He showed the phenomena of "nodes and antinodes" due to "stationary" waves

produced by reflection from the distant end, and says (in his lecture before referred to): "In my own mind, this verified Maxwell's theory; transmission along wires popularly sounds different from transmission in free space; but it was well known to me that the process was the same, and that the waves travel at the same speed, being only guided by the wires, much the same as sound is guided in a speaking tube."

Sir Oliver Lodge recorded these experiments together with the theory, and predicted the possible production of waves of much shorter wavelength, in the "Philosophical Magazine" for August 1888, and described them before the British Association at Bath during the same year (373).

In 1890 **Lecher** devised a parallel wire system by means of which stationary waves can be conveniently produced and demonstrated. This method is described by **T. Mizuno** in the "Electrician," August 7th, 1903.

HERTZ'S DISCOVERIES.—During the same year, 1888, **Heinrich Hertz,** a pupil of **Helmholtz,** who was a professor at Carlsruhe, in his paper "On the Action of a Rectilinear Oscillation on a Neighbouring Circuit," gave to the world the result of his epoch-making discoveries, and for the first time definitely established the existence of free electro-magnetic waves (125). He did not, however, describe them as waves, but as the "Outspreading of electric force." **Lord Kelvin,** in translating his work into English, designated them "Ether waves." During his first experiments he was not fully acquainted with **Maxwell's** theory, but he soon saw that therein lay a complete explanation of all his phenomena.

The following is a brief outline of his experiments: A in Fig. 32 represents the simple form of oscillator used by Hertz, consisting of two plates of metal, to which were attached rods or wires having, at their extremities, small metal knobs. These two knobs formed a spark gap. He connected an induction coil across the spark gap. This raised the potential of the knobs until the insulation of the air space between them broke down and a spark discharge took place. Each spark supplied by the coil produced oscillatory currents in the oscillator, of rapidly diminishing amplitude. These currents surged backwards and forwards across the spark gap until their original supply of energy was exhausted.

These rapid oscillations set up disturbances in the ether, which gave rise to a series of waves which carried off some of

the energy used to charge the oscillator. He also devised a method of detecting these waves (now known, after his name, as Hertzian waves).

This detector he termed a resonator. In one form it was an exact replica of his oscillator. It had the same dimensions, so that currents set up in it would have the same period of oscillation. This is represented by B, Fig. 32. When this resonator was placed in the neighbourhood of his oscillator corresponding electrical oscillations were set up and a spark took place between the knobs of the resonator.

Having created these free ether waves and detected their presence Hertz proceeded to investigate their properties. He noticed that the sparks at the detector were affected by the sparks of the transmitter, if the latter were placed within visible range of the former ; and he showed that this was entirely due to the ultra-violet light from the spark of the transmitter breaking down the insulation of the receiving gap and making it more conductive. This effect is now known to be due to ionization of the air.

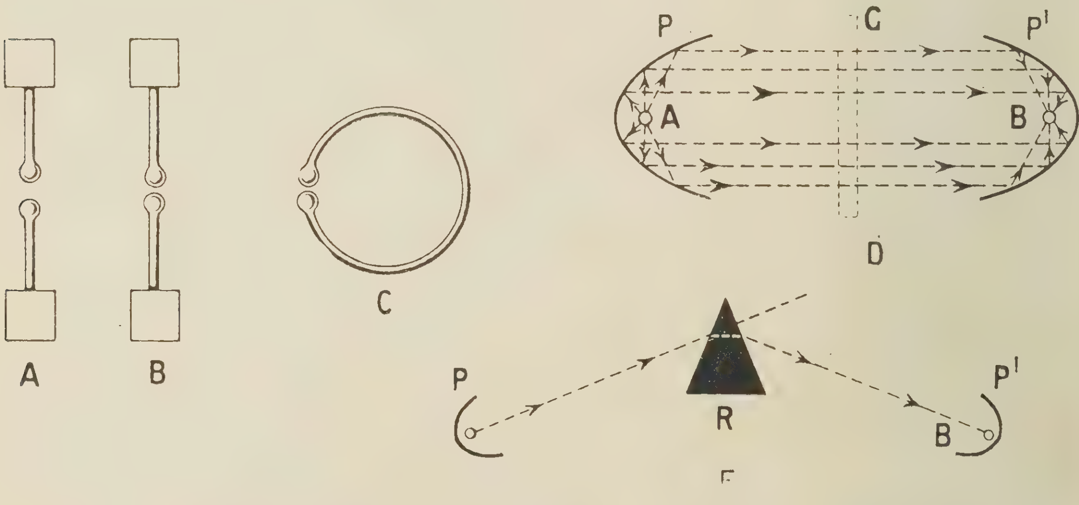


FIG. 32. Illustrating the apparatus used by Hertz in producing and detecting electrical oscillations, and in experiments with parallel beam radiation on very short wavelengths.

He discovered that the waves emitted from his oscillator obeyed all the laws governing optics, and he gave experimental proof that they travelled at the same velocity as light.

By means of a large screen of zinc, 8ft. square, which he placed against a wall of his laboratory, he was able to reflect the waves back and cause them to interfere with those coming from the oscillator and produce stationary waves with nodes and antinodes. When he moved a wire-loop detector C, as shown

in Fig. 32, to and fro between the screen and the oscillator, the sparks between the knobs of the detector disappeared at certain points, and reappeared in other positions, and again, on moving a little further, would disappear, and so on, indicating clearly that these radiations were of an undulatory character.

Hertz succeeded in producing some very short electric waves, 30 centimetres in length, and by placing a cylindrical reflector behind his oscillator he was able to concentrate the radiation into a parallel beam similar to a beam of light which, in exact accordance with Maxwell's theory, was propagated in straight lines like light. Fig. 32D illustrates this experiment, A and B being the transmitter and resonator, and P, P^1 being the reflectors.

Hertz showed that the beam would not pass through metallic objects, but was reflected by them, while it would pass through wood, stone, and many other substances. By placing metal screens in the direct line of the beam from the oscillator, he was able to show that a shadow space existed behind them in which no electric action was observable.

He showed, further, that his oscillator generated polarised electric waves, in which the direction of electric displacement was parallel to the line joining the plates, and he made an analyser to examine this polarised condition.

This consisted of a small wooden frame across which were arranged a large number of parallel wires forming a sort of grating. He showed that if this grating G were placed in the path of the beam so that its wires were parallel to the oscillator it effectively stopped the passage of the beam, whereas if the grid were placed at right-angles to the oscillator the waves passed quite easily through it.

He then demonstrated the refraction of Hertzian waves (24). For this purpose he employed a large pitch prism R, weighing 12 cwts., and deflected the ray from his oscillator, as shown in Fig. 32E.

He also showed that true waves were not emitted till beyond a quarter wavelength from the source of radiation.

Sir Oliver Lodge calculated (25), (374) that the radiating power of a small Hertz oscillator is, while it lasts, of the order of 100 horse power; but its duration is correspondingly short, for, at that rate, all its energy is expended in a single swing taking place in about one hundred millionth of a second.

The terms "Inductance" and "Self-induction," which are so familiar to the modern student, were unknown in the early days of wireless. **Lord Kelvin** spoke of it as electro-dynamic capacity, and made use of it as a mathematical co-efficient. **Maxwell** styled it "self-induction." The term "inductance" was first used by **Heaviside.**

In connection with the work of Heaviside it is interesting to note that it was he who pointed out the ionized condition of the upper atmosphere, termed later by **Dr. Eccles** (when postulating in 1911 his theory of wave transmission around the earth) "The Heaviside Layer."

The Dawn of Radio Communication.—Up to this point the transmission and reception of waves can only be said to have reached a point of high academic interest. Practical radio-telegraphy had not yet been achieved.

Hertz was once asked (4b) whether he thought telephonic communication would be possible by means of electro-magnetic waves, and he said that he considered it impossible, as the telephone was only capable of responding to comparatively slow alterations of current, and was incapable of responding to the high frequencies produced by electro-magnetic waves. This, of course, was correct, as no one (except **Hughes**, who had not published his results) had at that time devised a suitable detector.

In 1889 **Sir Oliver Lodge** delivered a lecture at the Royal Institution on "The Oscillatory Discharge of a Leyden Jar," and he demonstrated the phenomena of waves along wires, and in free space, with "recoil" and "overflow" effects; but he did not, at this lecture, show anything in the nature of signalling.

Sir William Crookes was present at the lecture, and in 1892 he wrote an article in the "Fortnightly Review" in which he foreshadowed telegraphic communication from one place to another across free space by means of electro-magnetic waves, and he suggested the possibility of tuning, so that many stations might signal simultaneously without interference. He said: "This is no dream of a visionary philosopher: all the requirements needed to bring it within the grasp of daily life are well within the possibility of discovery, and are so reasonably and clearly within the path of researches now being actually prosecuted in every capital of Europe that we may

any day expect to hear they have emerged from the realm of speculation into the realm of sober fact."

This prediction of tuning was five years before **Lodge** showed his great discovery of the Syntonic Jars, and demonstrated thereby how selective telegraphy could actually be achieved.

Professor Chunder Bose, of Calcutta, carried out a series of very useful experiments in the production of exceedingly short Hertzian waves, as did also **Professor Righi,** of Bologna, in Italy; it was under this latter professor that **Marconi** first became engaged in the study of wireless telegraphy.

RIGHI'S EXPERIMENTS.—Shortly after the discoveries of Hertz had been published **Professor Righi** * invented a very simple form of spark-gap, which was more easy to observe and more sensitive than the simple spark-gap between two metal knobs employed by Hertz. It consisted of a sheet of glass covered with tin foil, this foil being divided into several strips by a very fine razor cut. When used in place of the usual spark knobs of a Hertz detecting resonator, sparks appeared leaping from strip to strip over the gaps in the tin foil.

In a lecture delivered at Oxford on June 3rd, 1889, **Lodge** suggested the use of gilt wall paper or other interrupted metal surface as a detector in place of a spark-gap.

Righi also showed a method of exciting more vigorous oscillation by means of his "exciter." This consisted of three or, better still, four spheres immersed in an insulating oil, the central ones being much larger than those connected to the coil. The increased insulation of the oil in the spaces between the spheres required a greater electric strain to rupture it, and therefore caused the spark to be much more vigorous.

* A short summary of the life of Righi is given in reference (787).

CHAPTER V.

Wave Responding Devices of the Coherer Type

THE Coherer.—The invention of the Coherer by **Sir Oliver Lodge,** in 1889, marked a new era in the history of radio research. The phenomena of cohesion itself had already been observed as far back as 1850 by **Guitard** (26), who observed the coherence of dust particles in the vicinity of a static machine. One day, while looking at the particles of dust in a sunbeam, in his laboratory, he observed that whenever he worked his static machine the particles immediately formed together into little groups.

Varley's Lightning Protector.—In 1866 **S. A. Varley** noted the coherence of blacklead dust and finely powdered charcoal, and constructed a lightning protector for telegraph apparatus. This consisted of a small chamber, made of insulating material ; two wires entered this chamber, one from each side, and were so arranged as almost to touch one another. The chamber was then loosely filled with a powder composed of powdered carbon mixed with a certain proportion of a non-conducting powder. This little device was placed across the terminals of the telegraph instrument which it was desired to protect from the lightning, and, says Varley (4a) : " The lightning finds in its path a bridge of powder consisting of particles of conducting matter in close proximity to one another. It connects these under the influence of the discharge, and throws the particles into a highly incandescent state. Incandescent matter, as has already been demonstrated, offers a very free passage to electricity, and so the lightning discharge finds an easier passage across the heated matter than through the coils " [of the telegraph instrument].

He then gives his reason for the admixture of an insulating powder with the carbon, in which he clearly shows that he was conversant with the phenomenon of electrically-produced cohesion.

He says that although, under ordinary conditions, carbon powder used alone would offer an almost infinite resistance to the low-tension current employed for telegraphy, "when a high-tension discharge occurs the particles under the influence of the discharge will generally be found to arrange themselves so closely as to make a conducting connection between the

points of the lightning bridge. This can be experimentally demonstrated by allowing the secondary currents, developed by a Ruhmkorff's coil, to spark through a loose mass of black lead."

In 1870 Varley read a paper, before the British Association at Liverpool, in which he gave an account of a series of experiments he had conducted to show variations of resistance in loose masses of conducting powder (blacklead or fine charcoal powder). He first arranged a heap of the powder under test so as to bridge a small gap between two wires leading from a battery of 50 Daniell cells, and found that no appreciable current passed. He next increased the voltage by the employment of a battery of two or three hundred cells, and under these conditions, he said, "the particles arrange themselves by electrical attraction close to one another, making good electrical contact and forming a bridge through which the electrical current freely passes." Another of his experiments, which has acquired new significance in light of our modern knowledge of the emission of electrons from glowing filaments, was as follows: He placed masses of powdered blacklead and powdered wood charcoal in two crucibles, fitted with two electrodes, in similar manner to his "lightning protector," connected to a battery of 12 cells. So long as these were cold no current would pass through them, however close the electrodes were made to approach one another without actually touching. The crucibles were then heated to red heat, and electricity freely passed through the glowing powder.

Calzecchi-Onesti Cohesion Experiments.—In 1884 **Professor Calzecchi-Onesti** placed a number of copper filings on a brass plate. On the top of the filings he placed a second brass plate, and he showed that the filings were normally non-conductors, but that if pressure were applied they became conductive. Another of his experiments is of considerable historical importance. His observations were published in "Il Nuovo Cimento," October 15th, 1884, and March 2nd, 1885 (4a).

The tube he used in this research was very similar to the Branly Coherer, described later in this book. It consisted of a glass tube 35mm. long and 10mm. internal diameter, which was filled in the course of his experiments with various powders or metallic filings and was fitted at each end with a metal plug. It was arranged so that it could be revolved on its axis, in order to decohere the filings when required, and

was connected as shown at T in Fig. 33, in circuit with a telephone receiver P, a galvanometer G, and a small battery B. He arranged a form of short-circuiting key K across the telephone and battery, and he found that as long as the key was open only very small readings were recorded by the galvanometer, showing that the filings in the tube were offering a very high resistance to the passage of the current; but if he depressed the key and connected the telephone for a moment direct to the battery, and then broke the circuit by releasing the key, a sharp click was heard in the telephone and the galvanometer at once indicated a relatively large current, showing that the filings had stuck together, or cohered, thus becoming good conductors; he also found that when he revolved the tube upon its axis the filings fell apart again or decohered, again reverting to their non-conductive condition.

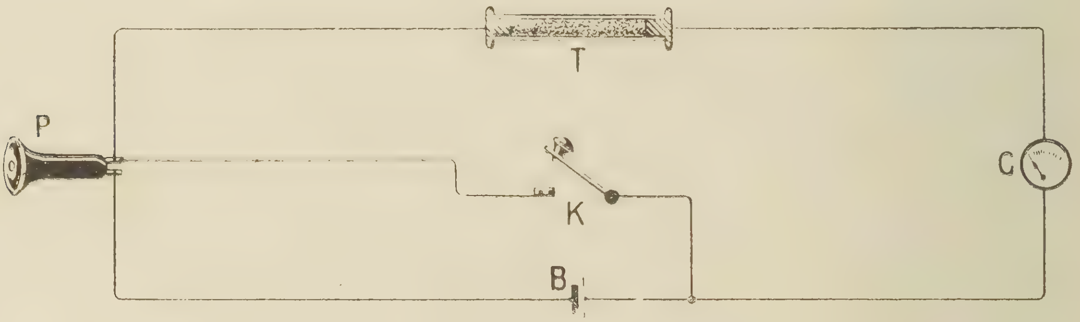


FIG. 33. The circuit used by Professor Calzecchi-Onesti for observing the properties of his Coherer.

He rightly attributed this change of conductivity to the extra current at the moment of breaking the key circuit. He repeated the experiment, using filings of various metals and different powdered substances, and he showed that contact with an electrified body or electro-static discharges would make the filings conductive.

MINCHIN'S IMPULSION CELL.—In 1888 **G. M. Minchin** * invented his "Impulsion Cell" (88), which, later on, was found to act as a detector of Hertzian waves. A strip of pure tin foil 1-inch long and $\frac{1}{8}$-inch broad is first cleaned with caustic soda, and then with dilute hydrochloric acid, after which it is washed in distilled water. It is then coated with a solution composed of 500 c.c. of distilled water, 3 c.c. of pure nitric acid, and 15 grammes of nitrate of ammonia. When the

* See also Murdock's photo-active electrolytic cells (730).

foil is covered with the solution a whitish deposit is thrown down on to its surface. This is allowed to form for about four minutes. The foil is then placed on a sheet of glass and heated uniformly by a spirit lamp until the liquid on the foil is all evaporated.

Continuing the heating process, the surface of the tin which bears the deposit assumes first a dull slatey appearance, then a whitish aspect, rapidly changing to a dark colour, with a tinge of green as the heating progresses, until finally, the green shade having passed over the foil, the dark surface becomes white. This stage having been reached, it is plunged into alcohol and is now in a very sensitive condition. If it is suspended by a platinum wire and placed in a cell filled with alcohol, in front of a similarly suspended clean tinfoil plate, and exposed to light, it is found that a small E.M.F. is generated, the sensitized foil being positive.

Mr. A. A. Campbell Swinton has shown (89) that selenium exhibits similar properties when made to form one unit of a simple primary cell. He immersed two carbon plates in ordinary tap water, one plate having its surface coated with a film of selenium. He connected a galvanometer across the plates and showed that in the light the selenium is electro-negative to the carbon plate, but when the cell is placed in the dark the condition is reversed.

Minchin discovered that these " Impulsion " cells (as he named them) had their sensitiveness altered by slight impulses or taps, and also by electro-magnetic impulses, such as are produced by sparks from a Hertzian oscillator at a distance.

He began his photo-electric researches as early as 1877, and discovered many interesting phenomena.

The following brief summary of his work in this direction is quoted from an article which appeared in " Nature " (369) in 1914, shortly after his death : " He observed that electric currents are produced by the action of light on silver plates coated with collodion or gelatine emulsions of bromide, chloride, iodide, or other silver salts, or with eosin, fluorescin, or other aniline dyes, when the plates were immersed in a suitable liquid and one plate was illuminated while the other was screened.

" In 1891 he exhibited these cells to the Physical Society and also cells made by spreading melted selenium on metal plates and immersing them in liquids with an uncoated plate. . . .

The form of photo-electric cell afterwards adopted by Professor Minchin consisted of two selenium-coated aluminium wires dipping into certain solutions. His ' Seleno-aluminium Bridges,' described in a paper to the Royal Society in May 1908, consisted of two plates of aluminium separated by a very thin flake of mica, and having a thin layer of sensitive (or conducting) selenium spread across one edge of the mica and the two adjacent portions of the aluminium plates. . . .

" Professor Minchin's application of selenium cells to the measurement of star-light was a notable extension of these experiments. In 1894, in conjunction with W. E. Wilson, he used his cells to obtain measurable electro-motive forces from the light of planets and stars, and was thus able to determine the relative intensities of the light of Jupiter, Venus, and Sirius. Shortly afterwards, an improvement in the construction of the cells enabled measurements to be made of the E.M.F.'s of the light of Vega, Arcturus, Regulus, Procyon, and other stars. A comparison of the results obtained by photo-electric measures with those of photo-metric measures of stellar magnitude showed close conformity."

Lodge's Coherer.—In 1889 **Lodge** showed that if two small metal spheres were arranged in extremely close proximity so that they were only separated by a most minute film of air (see Fig. 34) the current from a small battery was unable to pass between them, as proved by the fact that no reading was observable by means of a galvanometer which he placed in the circuit. When, however, a Leyden Jar was suddenly discharged in their vicinity the air film was broken down and they cohered, making electrical contact with one another and allowing a current to pass through the galvanometer.

This experiment was described in the year 1890 before the Institution of Electrical Engineers, and an account appears in the proceedings of that Institution of that year.

The diagram on the right of Fig. 34 represents another form of coherer, also devised by Lodge, at about that date, in which the coherence takes place at the contact between a steel watch spring and an aluminium plate. Critical adjustment is made by altering the tension of the spring.

A modified form of this detector is shown in Fig. 35. This detector* consists of a contact between a fine metal point P and a length of watch spring S and S_1, which is decohered by

* This was described in his U.S. patent No. 674846, May 21st, 1901. Patent applied for December 20th, 1897.

the vibration produced when a cogwheel W revolves against the end of the spring. He also employed an aluminium bar in place of the watch spring.

Another extremely sensitive form of coherer, known as Lodge's Disc Coherer, is described in Chapter VIII.

THE BRANLY COHERER.—In 1890 **Professor Branly** verified Onesti's observations, and showed the very important further fact that filings could be made to cohere by an electric discharge taking place in their vicinity (70).

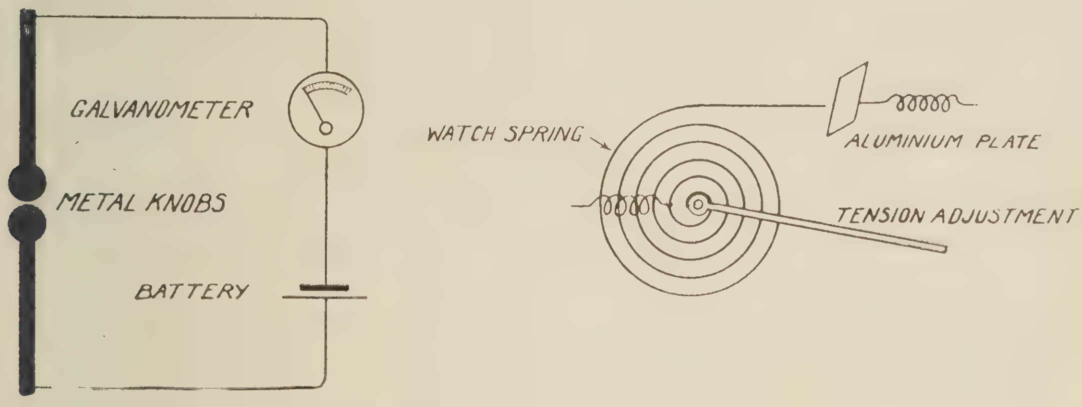


FIG. 34. Two forms of Coherer devised by Sir Oliver Lodge.

He described his researches in "La Lumière Électrique," May and June 1891, and he showed that metal filings could be decohered by a slight concussion. **Lodge** was the first to realise the importance of this fact; he introduced improvements in the Branly Coherer and obtained a considerable increase in sensitiveness, and in 1894 devised a mechanical tapper to bring the filings automatically to their normal non-conductive condition again after cohesion had been produced.

Lodge exhibited his apparatus before the British Association at Oxford in 1894, and received signals across a distance of 150 yards; but, strange to say, the idea did not then occur to him that he there had an instrument which might be turned to practical use for long-distance radio-telegraphy.

Tesla also took out a U.S.A. patent for a coherer. He employed a vertical tube containing oxidised metal filings, and he obtained decoherence by turning the tube upside down. He also made a coherer in which the filings were placed in a chamber exhausted of air, and in a later patent he maintained decoherence by keeping it constantly revolving, and he found that in this condition it would cohere momentarily during the passage of a wave.

In 1902 **Branly** made another coherer in the form of a tiny tripod, having steel points at the end of each leg. He stood this upon the polished surface of a flat plate of steel. Under normal conditions no current passed between the tripod and the plate, but in the presence of the Hertzian wave coherence took place. He arranged his recording apparatus in such a way as to jar the plate immediately the wave had passed, thus effecting decoherence.

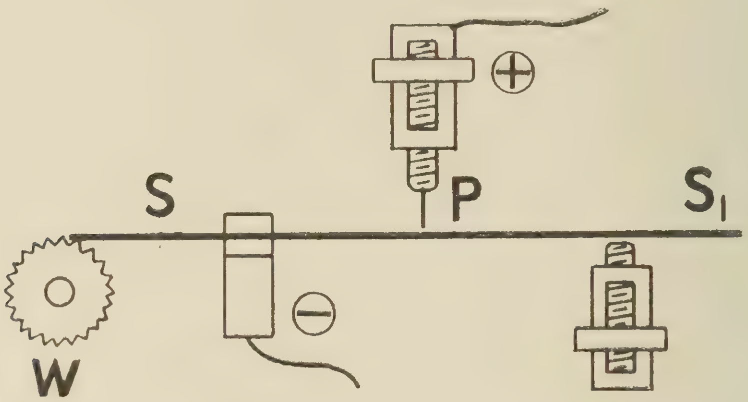


FIG. 35. A Coherer due to Sir Oliver Lodge, in which coherence takes place between a fine point P and the flat spring SS1.

THE ANTI-COHERER.—In the case of coherers the effect of a Hertzian wave is to cause an increase in their conductivity. We now come to another type of detector known as the Anti-Coherer, in which the reverse action occurs. There are several different kinds, which are described later in this chapter.

Schäfer's is probably the most curious, and is mentioned here as it has a certain similarity to the detector of Righi, mentioned in the previous chapter. Schäfer made a fine scratch across a strip of silver, chemically deposited on glass ; he connected the silver on one side of the scratch to one pole of a 4-volt battery, and completed the circuit through a galvanometer to the silver on the other side of the scratch. The galvanometer showed a steady reading of quite considerable amount.

Upon examining the scratch with a microscope the fact was revealed that the small detached particles of silver in the gap were in a state of great activity, oscillating to and fro, from one side to the other, acting as carriers of a "convection" current, on the principle of the " Electric Hail " experiment, shown in

elementary textbooks of Electricity (3). Under the action of a Hertzian wave the motion stopped and the current was arrested.

This form of detector has been used for the actual reception of signals. When used for this purpose the two silvered portions, separated by the scratch, were connected between earth and aerial, and the current changes were detected by means of a telephone. It was shown later, in 1899, by Neugeschwender (88), (92), that an increase of sensitiveness could be attained by bridging the gap with a film of moisture. It then functioned as an electrolytic detector, somewhat similar to that of De Forest, described in a later chapter.

An anti-coherer can also be made by forming a connecting bridge of silver, about 0.1mm. wide, in a very wide gap, the whole being coated with collodion (1).

Popoff's Coherer and Tapper (4a).—This was designed for recording atmospheric disturbances and was described by *Popoff* to the Physico-Chemical Society of St. Petersburg in April, 1895.* In December (4a) of the same year he predicted that if a sufficiently powerful transmitter could be devised his apparatus might be perfected and used to receive signals.

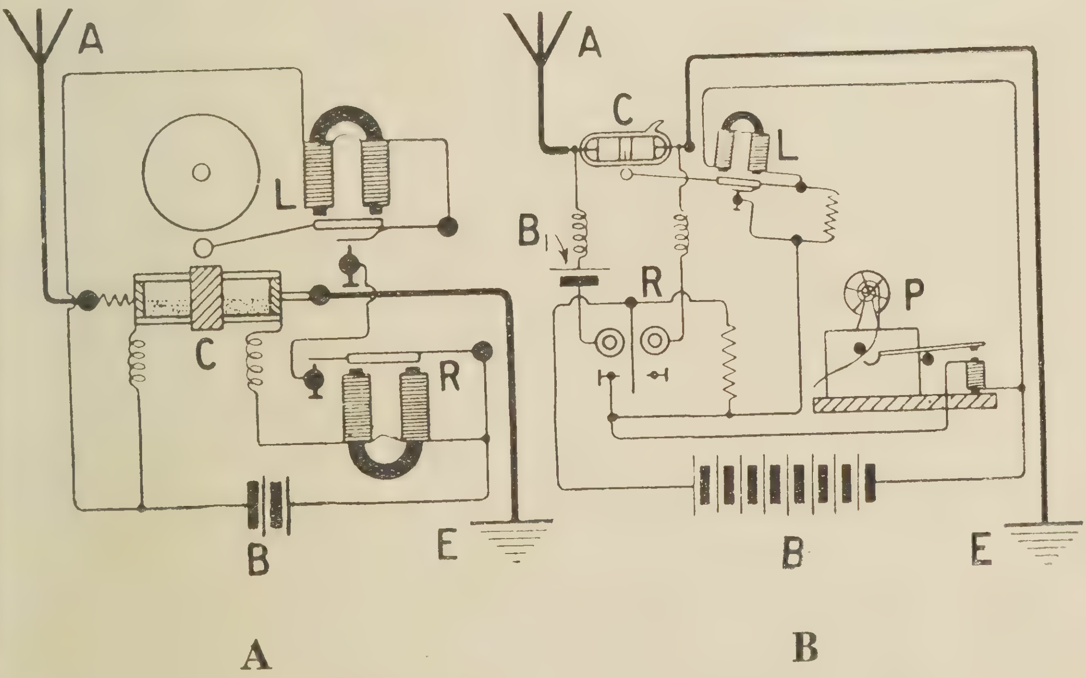


Fig. 36. Early Cohering devices, of Popoff (A) and Marconi (B).

*For description see (Ref. 4a) also "Elektritchestvo," St. Petersburg, July, 1896.

G

Marconi's Coherer and Tapper.—Earlier in the same year, 1895, *Marconi* invented his coherer and decohering circuits.* Fig. 36 represents the coherer circuits of Popoff and Marconi. The similarity is, the Author believes, a coincidence. The former was originally designed for recording atmospherics while the latter was intended for reception of wireless signals.

(A) *Popoff's* circuit. C is the coherer containing loosely packed metallic filings. L is an electric bell which serves as a decoherer. R is a simple relay and B is a battery supplying all the circuits.†

(B) *Marconi's* circuit. C is the coherer and L is a tapping device. B_1 is a small battery actuating a delicate relay through the coherer. B is a larger battery actuating the tapper and recording instruments.

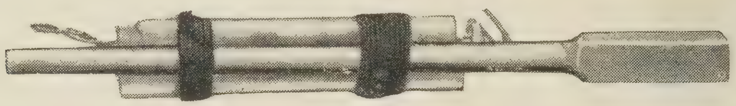


Fig. 37. An early type of Marconi Coherer. *(By courtesy of the Marconi Co.)*

Fig. 37 is a photograph of an early form of Marconi coherer. The filings used in his early coherers consisted of 96 per cent. of nickle to 4 parts of silver to which was sometimes added a trace of mercury. The tubes were exhausted to about 1/1,000 of an atmosphere.

Fig. 38 shows Marconi's transmitter and receiver.‡ It is interesting to see how nearly Dolbear accidently came to Marconi's transmitter. See Fig. 30. They both employed aerials, earth connections, primary batteries, Ruhmkorff coils, and Morse keys ; but here the similarity ends for by the employment of a Righi oscillator (across the secondary terminals of his coil) between earth and aerial, Marconi

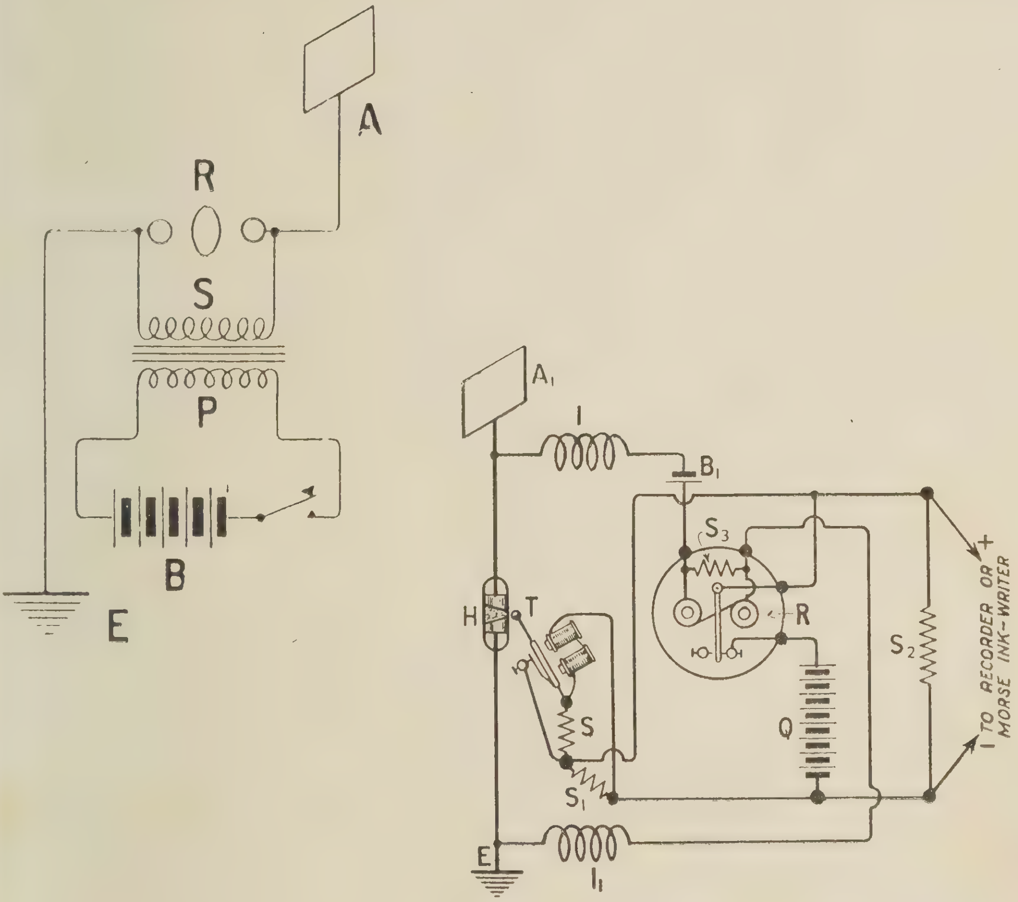
*Patent No. 12039/96. This patent was applied for June 2nd, 1896. Complete specification lodged March 2nd, 1897, and accepted July 2nd, 1897.

†It should be noted that the voltage of B must be kept low to avoid self-coherence of the coherer circuit. Marconi avoided this by employing a separate battery to energize the tapper and recording instrument.

‡In 1898 (Ref. 28) using small transformers in connection with condensers Marconi tuned his coherer circuit, thus greatly increasing the range and reducing interference between communicating stations.

excited electrical oscillations in the aerial at radio-frequencies which became a source of electro-magnetic waves in the ether that travelled out into space at the speed of light.

Dolbear's receiving apparatus would not have recorded their presence. These waves in passing by a Marconi receiving station set up electrical oscillations therein at radio-frequencies, so that when signals arrived, changes of potential occurred



MARCONI

FIG. 38. The transmitting and receiving apparatus employed in Marconi's early experiments.

between the ends of coherer H, Fig. 38. The filings cohered, became conductive, and allowed a weak current to pass through them and operate a relay R which switched on a larger current from battery Q, operating the tapping device T, This decohered the filings by shaking them, and left the whole arrangement ready for reception of the next signal.

A rough analogy may help to explain the difference between the transmitters of Dolbear and Marconi.

In Dolbear's case the free electrons in the aerial oscillated comparatively slowly, their movements strained the ether in the vicinity, but were too slow to set it into a condition of wave motion. The action was comparable to the slow movements of the jelly referred to in Chapter 1 Fig. 1 and the ether strains (or electro-static field) were only able to effect Dolbear's receiver at short range and he did not apparently even realize the possibility of setting the ether into a state of wave-motion. Apparently he did not realise that the ether played any part in the performance, but tried to account for his results by attributing them to changes of electrical potential in the earth in the neighbourhood of each station.

We can imagine a line of force in the ether, attached to a single electron in the aerial, and picture the electron oscillating slowly up and down the latter, and as an analogy we can consider the action of a straight length of rope on the ground. We can pick up one end, lift it slowly, and replace it. By this means we may move a few yards of the rope from the ground, but no wave-motion will be produced and the movement will not travel to any great distance.

On the other hand, we can lift the end of the rope violently and replace with equal speed. In this case the whole rope receives a jerk and a wave-motion travels along it to its far end. This is the nature of the action in Marconi's Transmitter. By the employment of the spark-gap between earth and aerial he increased enormously the frequency of the oscillations of the electrons in the aerial and produced actual wave-motion in the ether.

SIR HENRY JACKSON'S RESEARCHES.*—In 1895 **Captain Jackson, R.N.** (who afterwards became First Sea Lord), commenced carrying out experiments between ships in the Royal Navy. His experiments were at that time confidential, and, knowing nothing of the work of Lodge, Hughes, Marconi, or other contemporary workers, he succeeded, in August 1896, in sending telegraphic signals between two ships, using a coherer with an electric bell acting as a tapper.

*The Royal Society in 1926 awarded the Hughes Medal to Admiral Sir Henry Jackson, G.C.B., K.C.V.O., F.R.S., DSc., M.I.E.E., for his pioneer work in the scientific investigations of radio-telegraphy and its application to navigation.

On September 1st, acting under Admiralty orders, he met **Mr. Marconi** at the War Office, and they compared results, which showed that they had both been working on identical lines, but with small differences in the details of the gear which they employed. The Post Office then joined in, and in the 1898 Naval Manœuvres telegraphy was successfully carried on to a distance of 60 miles.

In 1901 Admiral, then Captain, Jackson brought out a system of tuning, and succeeded (for the first time on record) in receiving simultaneously down the same aerial two different printed messages from two ships sending on different wave-lengths, 30 or 40 miles distant.

In 1904 Admiral Jackson took Marconi on board the battleship "Duncan" for his first long-distance wireless telegraph test for ships, and messages from them were easily received at Gibraltar.

MINCHIN'S RECEIVER.—At about this date **Professor Minchin** read a paper before the British Association at Belfast in which he described a receiver for Hertzian waves of self-decohering

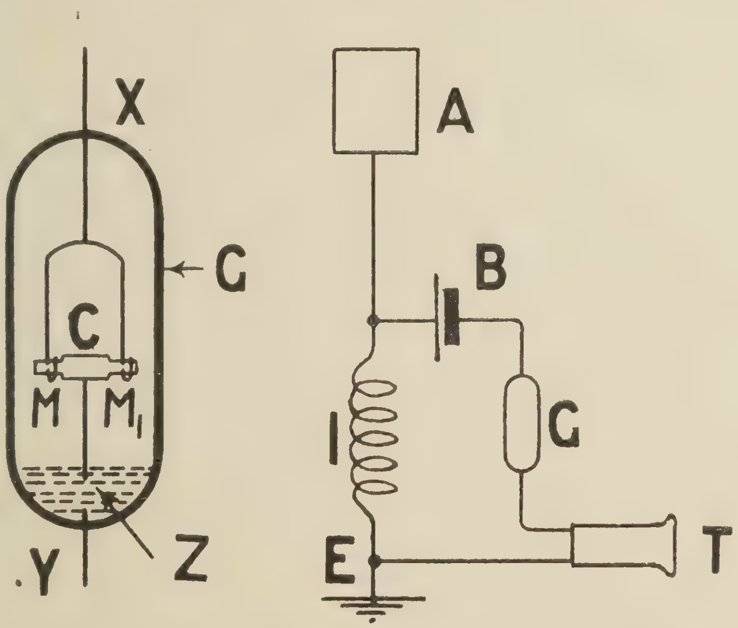


FIG. 39. Minchin's self-decohering detector and the circuit in which it was employed.

type, which he used in conjunction with a telephone. This is shown in Fig. 39, and consists of a small stirrup of aluminium wire M, M_1, on which rests a small cylindrically shaped piece of carbon C, from the centre of which a fine platinum wire

depends into a little pool of mercury Z in the bottom of a glass tube G. Wires X and Y are sealed into the top and bottom of the tube for connections. Before the tube is sealed at its upper end the mercury is boiled, so that the tube becomes filled with mercury vapour, and in this condition it is sealed. The mercury vapour then condenses, thus exhausting the tube.

In use, Minchin connected the apparatus up as shown on the right-hand side of Fig. 39, where A is a sheet of metal forming a capacity aerial, I an inductance, B a small battery, G Minchin's receiver, T a telephone, and E an earth connection

When used in this manner in conjunction with a telephone it was sufficiently self-restoring to reproduce signals in the telephone without tapping ; when used in conjunction with a relay, however, tapping was found to be necessary.

ROVELLI'S SELF-RESTORING COHERER.—In 1898 **Signor Rovelli** made a detector in which he used iron filings, which he found were to some extent self-restoring.

CHUNDER BOSE'S EXPERIMENTS.—Between 1899 and 1900 **Chunder Bose,** of Calcutta, tested the coherence of nearly all metals and found that, while they all cohered, potassium possessed the property of self-decoherence, but had to be used under paraffin oil, or in a vacuum, to avoid oxidization (1019).

JERVIS-SMITH'S COHERER.—In 1897 **Professor Jervis-Smith,** of Oxford University, succeeded in telegraphing over one mile, using a carbon powder microphone as a detector (almost identical with that devised and used by **Hughes**). See Fig. 27.

It is very interesting to observe the close resemblance in form between this and the later forms of coherer devised by **Popoff** and **Marconi.** This instrument has been termed a micro-radiophone.

FERRIÉ'S COHERER.—In 1897 **General Ferrié** invented a coherer, using gold filings, the quantity of which was capable of regulation.

Similar coherers, in which the quantity of filings used could be regulated, were employed by **Blondel** in 1898 (see the "Electrician," vol. xliii.) and also by **Lodge.**

Popoff's Microphonic Contact Detectors.—In Russia, **Popoff**, in 1900, employed microphonic contacts between steel needles and carbon plates, and used microphonic detectors containing steel filings and carbon powder.

Shoemaker's Detector.—**Shoemaker**, of Philadelphia, invented a detector which consisted of a number of steel balls in a horizontal line, the spaces between the balls being filled with carbon powder.

In 1902 Messrs. **Shoemaker** and **Pickard** took out a U.S.A. patent for a wave-responsive device, using steel needles supported at each end by two carbon discs. It was an elaboration of the **Popoff** microphonic receiver, and very similar to the receivers used by **Hughes.**

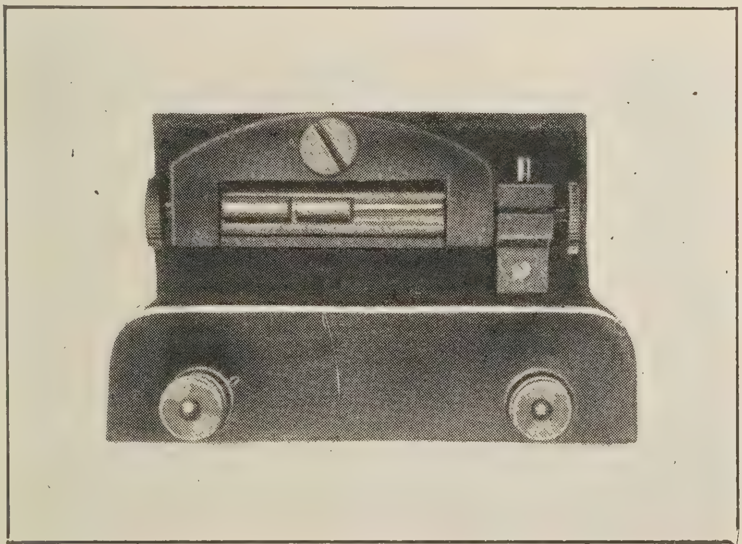


Fig. 40. The detector used by Marconi for transatlantic reception in 1901.

Tommasina's Self-restoring Coherer. We now come to a very important type of detector, which is of particular historical interest as it was a detector of this type which Marconi employed during his first transatlantic receptions.

In 1899 **Professor Thomas Tommasina**, of Geneva, invented a self-restoring coherer consisting of a tiny globule of mercury in a tube between plugs of carbon and iron. He showed it before the Geneva Physical Society in 1899, and published

an account of it in the " Rendus de l'Académie des Sciences " for May 1st of that year. This invention was later wrongly attributed to **Castelli,** who employed it in the Italian Navy in 1900, and again, in 1902, **Luigi Solari** used this detector and named it " **The Italian Navy Detector.**"

Fig. 40 is a photograph of the actual detector of this type used by Marconi in place of his coherer in his first transatlantic receptions in 1901. This historical instrument is now in the keeping of the Institution of Electrical Engineers, and is reproduced by their kind permission (62).

Fig. 41 is a diagram showing the construction of the Italian Navy detector. G is a glass tube fitted with two carbon plugs C and C_1; in the centre is an iron plug I. M and M_1 are globules of mercury.

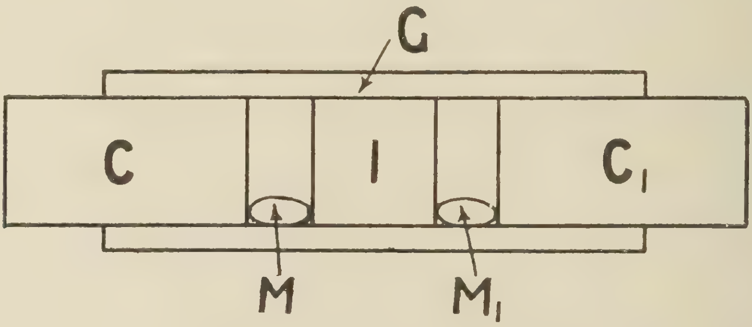


FIG. 41. A diagrammatic representation of the Italian Navy detector.

SLABY'S SELF-RESTORING COHERER.—**Dr. Slaby,** who, working in conjunction with **Professor Braun** and **Count Arco,** was the originator of the Telefunken System (28), invented a coherer of the self-restoring type. It consisted of a number of steel balls, lying loosely between aluminium plates. This was described in an article by **A. F. Collins** in "The Scientific American " of December 28th, 1901.

CHAPTER VI.

Wave Responding Devices of the Magnetic Type

As already stated earlier in this history, **Joseph Henry,** in 1842, succeeded in demagnetising steel needles by Leyden Jar discharges.

In 1895 it occurred to **Rutherford** that it might be possible to make use of this phenomenon as a means of detecting electric waves, and in that year, using a large Hertzian Oscillator, he was able to detect the radiations at a distance of three-quarters of a mile. The rods of his resonator were connected to a small bobbin of fine wire, in the centre of which was placed a magnetised steel needle. He arranged a magnetometer to measure its degree of magnetisation before and after a spark had taken place at the distant transmitter, and he found that it had become demagnetised by the received oscillations and had to be remagnetised before the experiment could be repeated.

In 1900 he suggested to **Dr. Erskine Murray** (see Erskine Murray's "Handbook of Wireless Telegraphy") that the oscillations might be made to record themselves on a steel band, as in the telegraphone, invented later and employed by the Poulsen Company (see description in Chapter XIV.).

In 1897 **Professor E. Wilson** constructed an automatic magnetic detector on the same lines as those adopted by Rutherford (see also references to his later patents, 166), but he arranged that the movement of the magnetometer needle, at the moment of demagnetisation of the steel needle in the bobbin, closed a local battery circuit and remagnetised it.

Fessenden's Magnetic Receivers.—In 1902 **Fessenden** invented several forms of magnetic detector. One form is shown in Fig. 42A. It consisted of a silver ring S, resting on two steel knife edges K and K_1, and of a block of carbon C, the tension of the latter against the under side of the ring being adjustable by means of a setscrew. The aerial was connected through a small coil of wire, and the received oscillations set up an electric field in the neighbourhood of this coil, which controlled the pressure of the ring S against the carbon block. A weak alternating current was supplied to the phone from a source B, producing a sustained buzzing note the intensity of which was varied by the changes of resistance between S and C.

Fig. 42B shows another of Fessenden's electro-magnetic detectors, the working of which also depends on the action of the electro-magnetic field produced by the incoming oscillations as they pass through a helix of wire, upon a closed circuit, in the form of a light ring of wire. No iron or steel is used in this detector. A indicates the aerial, B and B_1 the helix, R the metal ring suspended from Q by means of a fine fibre. The signals are read from the movements of a beam of light reflected from a small mirror M. C is a small condenser connected across the helix.

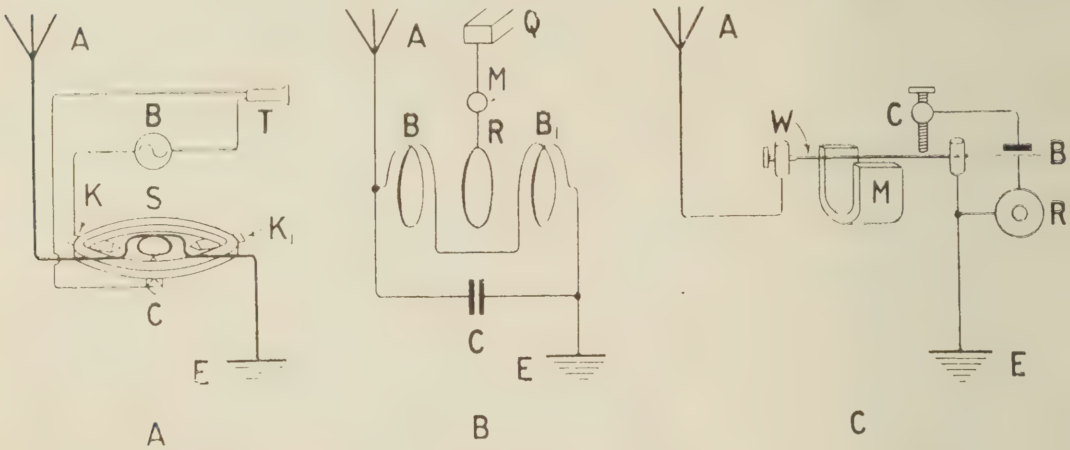


FIG. 42. Some forms of magnetic detector invented by Fessenden.

Fig. 42C shows another magnetic receiver due to Fessenden. The aerial A leads the received oscillations through a fine steel wire W, which is being attracted downwards by the powerful magnetic field of a permanent magnet M, so that it sags slightly. The oscillating currents through the wire for a moment destroy the action of the magnetic field, and the wire springs up and touches a contact C, momentarily closing a local circuit, which includes a recording instrument R.

FESSENDEN'S HETERODYNE RECEIVER.—Another of Professor Fessenden's inventions for the reception of radio-telegraphic signals was his " Heterodyne " receiver, shown in diagram 43A. This is made up into similar form to an ordinary " Bell " telephone receiver. This method of reception was proposed by Fessenden in 1902. (Refer also to Chapter XIV. : The Work of R. A. Fessenden.)

It consists of two bobbins of wire B and C wound round a fixed iron wire core, in front of which is arranged an iron diaphragm. The received oscillations which arrive at a frequency above audition pass through coil B to earth. Coil C

is supplied with a high-frequency alternating current, from a local source V, the frequency of which can be varied in order to produce audible beat notes of any desired frequency. Fessenden has termed the little generator which he uses for this purpose a " Heterodyne."

In another form of Heterodyne receiver Fessenden retains the soft iron core with one bobbin of wire wound round it, and attaches the other bobbin of wire to a mica diaphragm so that it is free to vibrate over the iron core. In the " Radio Review " for January 1921 **Latour** describes another and more simple arrangement for heterodyne reception, in which he says : " By using, in the magnetic circuit of the telephone, very fine wire, such as is now obtainable commercially, the windings may be combined in one." (See Fig. 43B.)

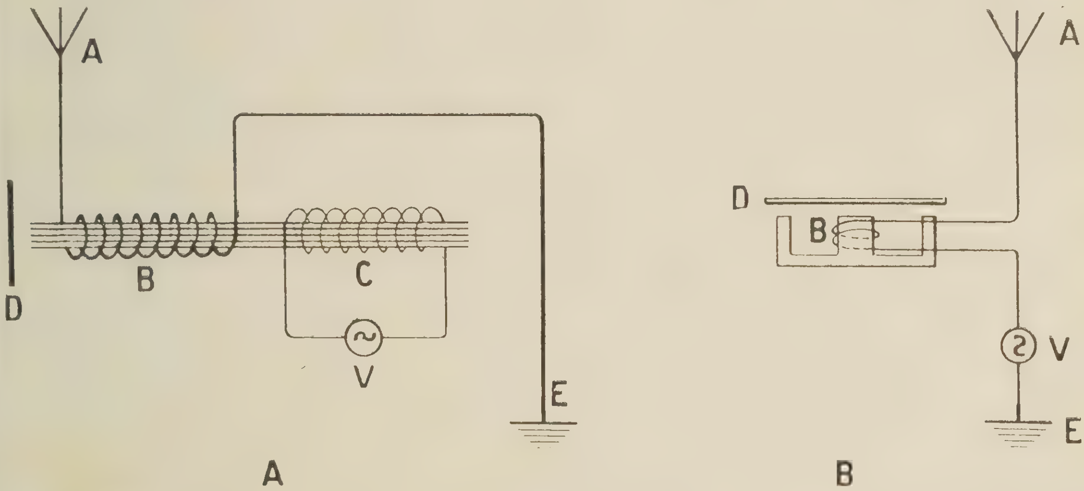


FIG. 43. The circuit diagrams of the " Heterodyne " receivers due to Fessenden (A) and Latour (B).

In 1904 **Marius Latour** suggested the production of audible signals by the employment of beats between two simultaneous radiations of differing frequencies from two adjacent transmitting stations (29), and to receive them by means of the electro-dynamic telephone, described by Leblanc in " La Lumière Électrique " of April 17th, 1886. This instrument was based on the principle of the electro-dynamometer, and consisted of two circular parallel coils connected in series, one attached to the underside of an ebonite diaphragm and the other fixed just below it. Variations in the intensity of a high-frequency current passing through these coils caused corresponding variations in the attractions between the two coils and produced vibrations of the diaphragm.

For Marconi's patents see ref. nos. (403) to (405) ; see also E. Wilson's patents (166) and S. Cabot's patents (167).

Marconi Magnetic Detector.—In 1902 **Marconi** patented two forms of magnetic detector (see Fig. 44 A and B), the originals of which are now in the possession of the Institution of Electrical Engineers. These have been called "Hysteresis" detectors. Before describing them a brief explanation of the principles involved may be helpful. When iron is magnetised by means of an adjacent magnet or by the passage of a current through a surrounding coil of wire it does not become magnetised to its full extent instantly, but there is an appreciable time-lag behind the applied magnetising force. If the iron receives a sudden blow its molecules are shaken up and the lag instantly disappears, the iron becoming at once fully magnetised. The same thing happens to the iron in the presence of a high-frequency alternating field.

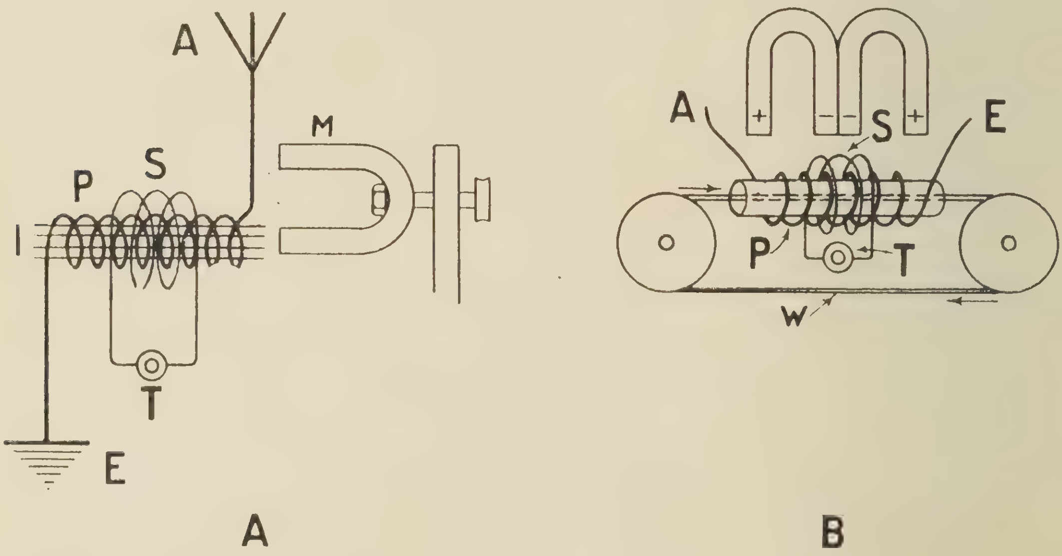


Fig. 44. Marconi magnetic or "Hysteresis" Detector. The moving member is in A a permanent magnet, and in B a band of soft iron wires.

Fig. 44A shows the arrangement of Marconi's first magnetic detector. I is a fixed iron core composed of fine soft iron wires ; round this are wound two coils of wire, a primary P connected to aerial A and to earth E, in which high-frequency oscillations occur during the reception of each wave train ; a secondary S is connected to a telephone T.

M is a permanent steel magnet, which is revolved by clockwork. The effect of this is to reverse periodically the magnetic polarity of the iron core ; but there is a lag in time behind

this magnetisation and the movement of the magnet M. Every time a wave arrives and a high-frequency current flows through the primary P the iron core suddenly becomes fully magnetised, and the sudden change in the distribution of the magnetic field produces an E.M.F. in the secondary circuit which actuates the telephone receiver T.

Fig. 44B shows Marconi's second form of magnetic detector (see also photograph, Fig. 45). An endless band of

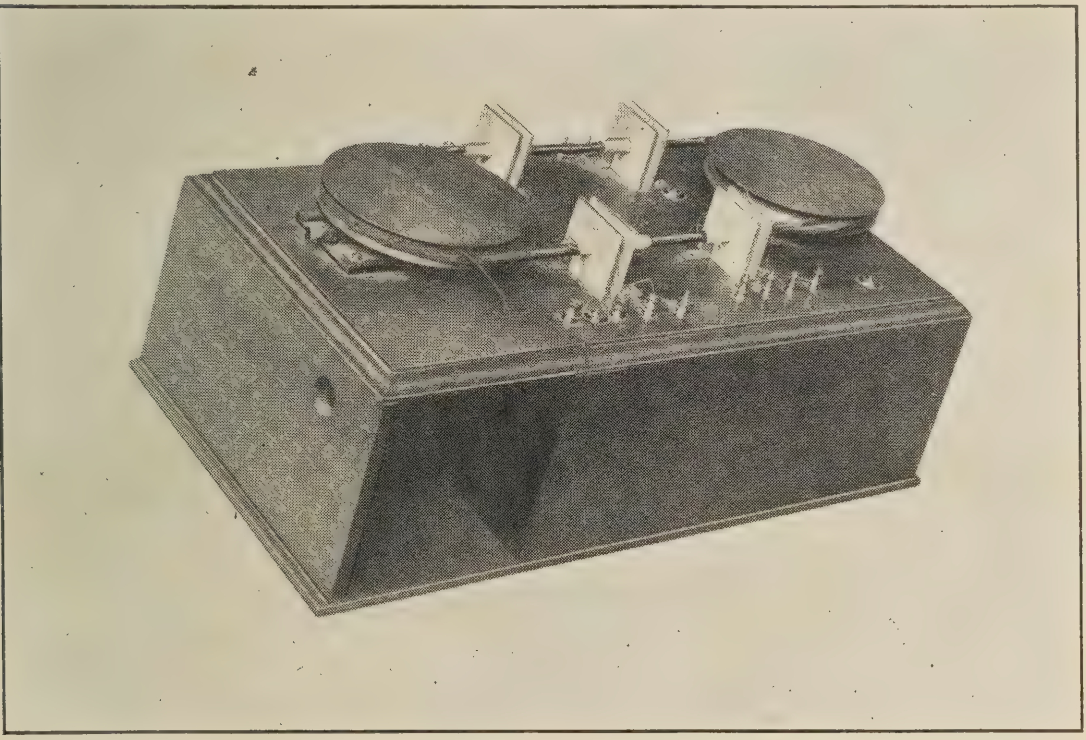


FIG. 45. A magnetic detector as designed for commercial use.
(*Courtesy Marconi Co.*)

insulated soft iron wires W is kept moving at about 5 inches per second past the poles of two permanent magnets. A small glass tube surrounds the iron wire just in front of the poles of the magnets. On this is wound a primary and secondary. In the absence of oscillations through the primary P, the lines of magnetic force are, so to speak, pulled out of position by the moving band of iron, which, by its steady progression, is being taken away from the poles before it has had time to become fully magnetised. If now the iron band is given a sharp blow, or if oscillations pass suddenly through the primary P, the iron suddenly becomes fully magnetised and the lines of force move back into the position they would occupy were the band stationary. This sudden movement of the lines of force creates a momentary current in the secondary coil, which causes a sound to be heard in the telephone.

The originals of both of these detectors are shown in a photograph of Marconi's early apparatus, in the keeping of the Institution of Electrical Engineers (Fig. 63, Chap. VIII).

Fig. 45 shows a commercial type of magnetic detector.

Braun's Magnetic Coherer.—This instrument consists of two steel plugs in a glass or ebonite tube, between which is placed a quantity of steel filings. One of the steel plugs projects from the tube and is placed between the poles of a horseshoe magnet, the latter being movable in such a way that one or other of its poles can be brought near the electrodes. By adjustment any required degree of magnetisation can be applied to the filings in the coherer and its sensitivity adjusted to a maximum.

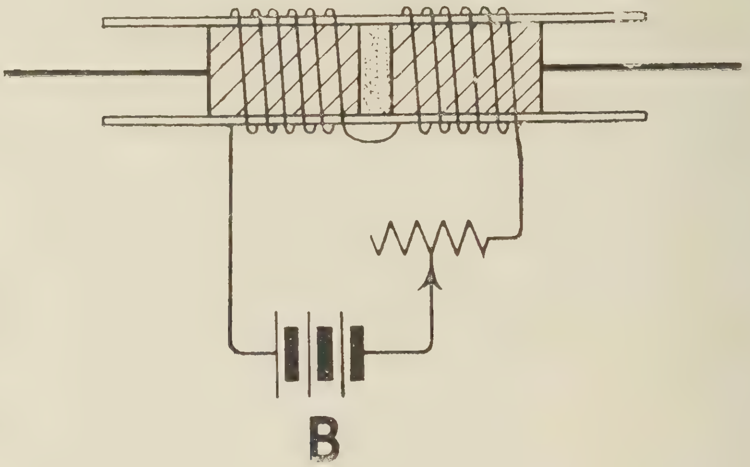


Fig. 46. The "Teppuri" detector invented in 1904 by M. Saiki.

Saiki's Teppuri Detector.—In 1904 (Japanese patent No. 11849) **M. Saiki** invented a detector called the "Teppuri" Detector (30). Fig. 46 shows its construction.

Two magnetised steel plugs are fitted into a glass tube, their distance apart being adjustable. In the space between them is placed a quantity of fine steel powder which has first been oxidised on its surface by burning in a flame. The ends of the steel poles are well polished, and a strong magnetic field is created through the steel powder by the aid of a battery B. The stronger the magnetic field, the better is the result.

In 1908 **Wichi Torikata** experimented with several mineral ores in place of oxidised steel in Saiki's "Teppuri" Detector, including magnetite, ironglance, etc.

Fessenden's High-frequency Receiver (256), (257), (50).—**Fessenden** has patents for a telephone receiver in which the received oscillatory currents are made to act directly on a

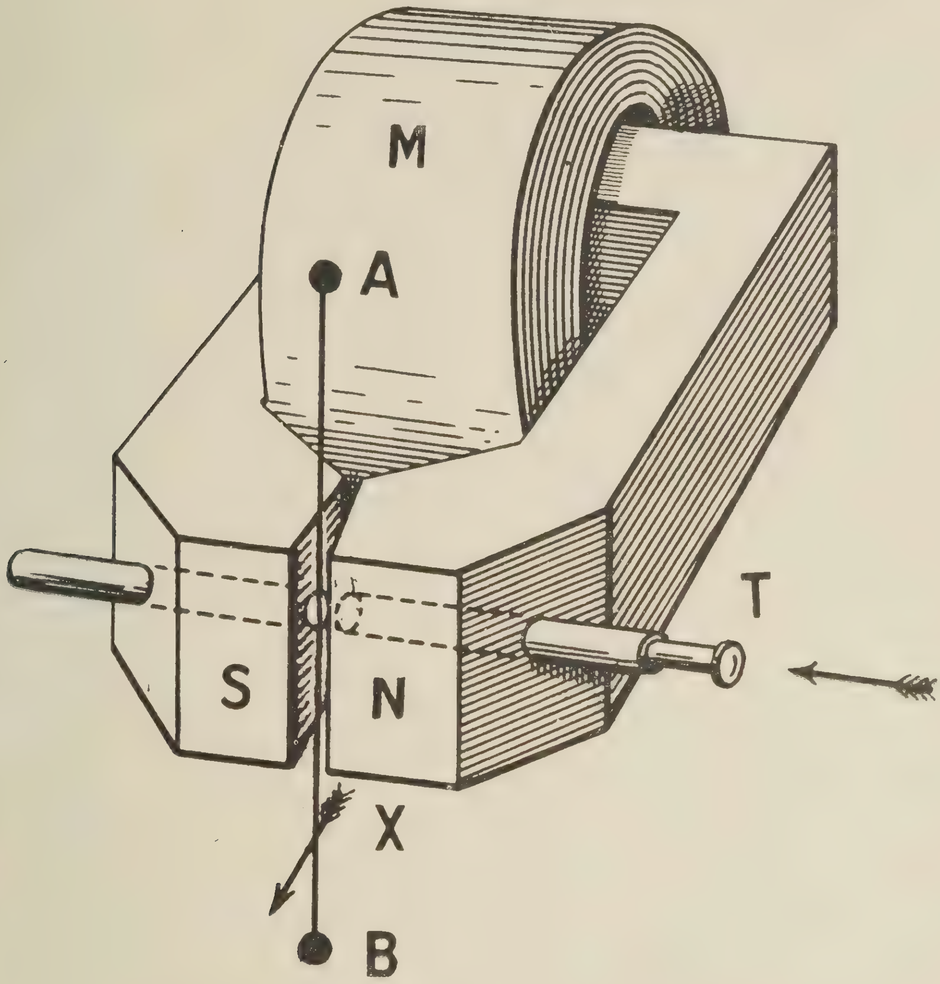


Fig. 47. A diagram of the Einthoven string galvanometer, employed by Marconi in high-speed reception.

metallic diaphragm. They pass round a solenoid containing only a few turns of wire connected in series (or parallel) with a condenser for tuning purposes, and the Foucault currents which are induced in the diaphragm, which is close to the end of the solenoid, set up vibrations in accordance with the variations of current.

Walter's Magnetic Detector.—In 1904 **Walter** and **Ewing** patented a magnetic detector based on the discovery that oscillatory currents travelling from end to end of a fine steel wire produce an increase in its hysteresis. The hysteresis changes are measured by a mechanical couple between either a fixed ring or winding of iron and a revolving magnetic field, or vice versa. When the field revolves the iron tends to be

pulled round with it, in consequence of hysteresis in the reversals of its magnetisation. The motion is checked by a spring, so that the iron assumes a deflected position. Under the influence of an oscillatory current hysteresis changes occur in the iron, causing corresponding changes in the amount of deflection. Several modifications of this instrument were described in the "Proceedings of the Royal Society," vol. lxxiii., 1904.

In 1906 **Walter** invented another form of magnetic detector, which, when excited by received oscillations, produced small unidirectional currents. For a description of this detector see "Proc. Royal Society," vol. lxxvii., April 1906, or (28).

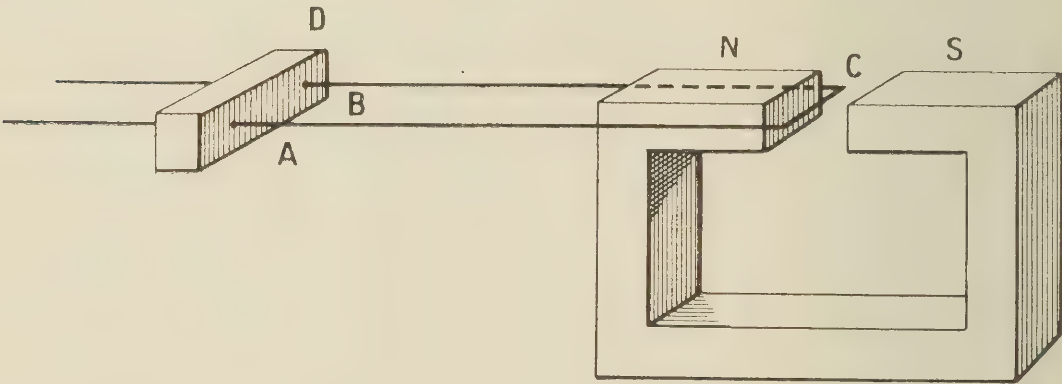


FIG. 47a. Illustrating the principle of Evershed's Call Relay.

THE SELLA-TIERI DETECTOR.—This detector, as invented by **Sella** and improved by **Tieri,** consists of a core of soft iron wires soldered together at their ends. These are fitted into a glass tube, from which they project a short distance at either end. A primary is wound on the outside of the glass tube and connected to earth and aerial, also a secondary connected to a telephone receiver. The iron core is continually twisted and untwisted by a mechanical arrangement, while a current is passing along it from end to end. While in this condition of varying torsion it is sensitive to oscillations in the primary. The changes in magnetisation produced thereby give audible sounds in the telephone.

THE EINTHOVEN STRING GALVANOMETER (4d) (Fig. 47).—For high-speed reception **Marconi** has employed the Einthoven String Galvanometer. The galvanometer itself consists of an exceedingly fine silvered glass or quartz fibre A B, suitably suspended between the plates N and S of a powerful electro-

agnet M. The fibre is placed in circuit with a rectifying rystal or other form of rectifying device capable of converting he incoming oscillations into unidirectional pulses.

When such a pulse passes from A to B the fibre is caused to ag slightly outwards in the direction indicated by arrow X. At slow speeds its movements can be viewed by means of a elescope T, or a shadow of the fibre can be projected by a powerful light and suitable lenses on to a moving photographic ilm. In this manner speeds up to 100 words per minute have been recorded.

Evershed's Call Relay (88).—Fig. 47a illustrates the principle of this device. A, B, C is a rectangular loop of fine wire fixed in an insulating block D. The end of the loop C is free to vibrate in the space between the poles of a powerful magnet N, S. When the loop is traversed by an alternating current it vibrates up and down. To increase its sensitivity the loop is tuned as to its length so that it may have the same period of oscillation as the current.

When so tuned it becomes a very sensitive voltmeter, the amplitude of its vibrations being proportional to the E.M.F. at the terminals of the loop. When employed as a relay a contact screw is arranged for the loop to come into contact with as it vibrates. A better method is to have two rectangular loops connected to separate secondary circuits in such a way that they oscillate in opposite phase. On the arrival of a signal the two loops come into contact with each other and complete the local circuit.

H

CHAPTER VII

ELECTROLYTIC AND CRYSTAL DETECTORS

AS already mentioned in Chapter V., **Neugeschwender,** in 1899 (27), (88), (92), increased the sensitivity of Schäfer's Detector by moistening the gap formed by a razor scratch across a piece of silvered glass. The action of this detector was electrolytic.

DE FOREST'S RESPONDER.—The first really practical electrolytic detector was probably that invented by **de Forest** and

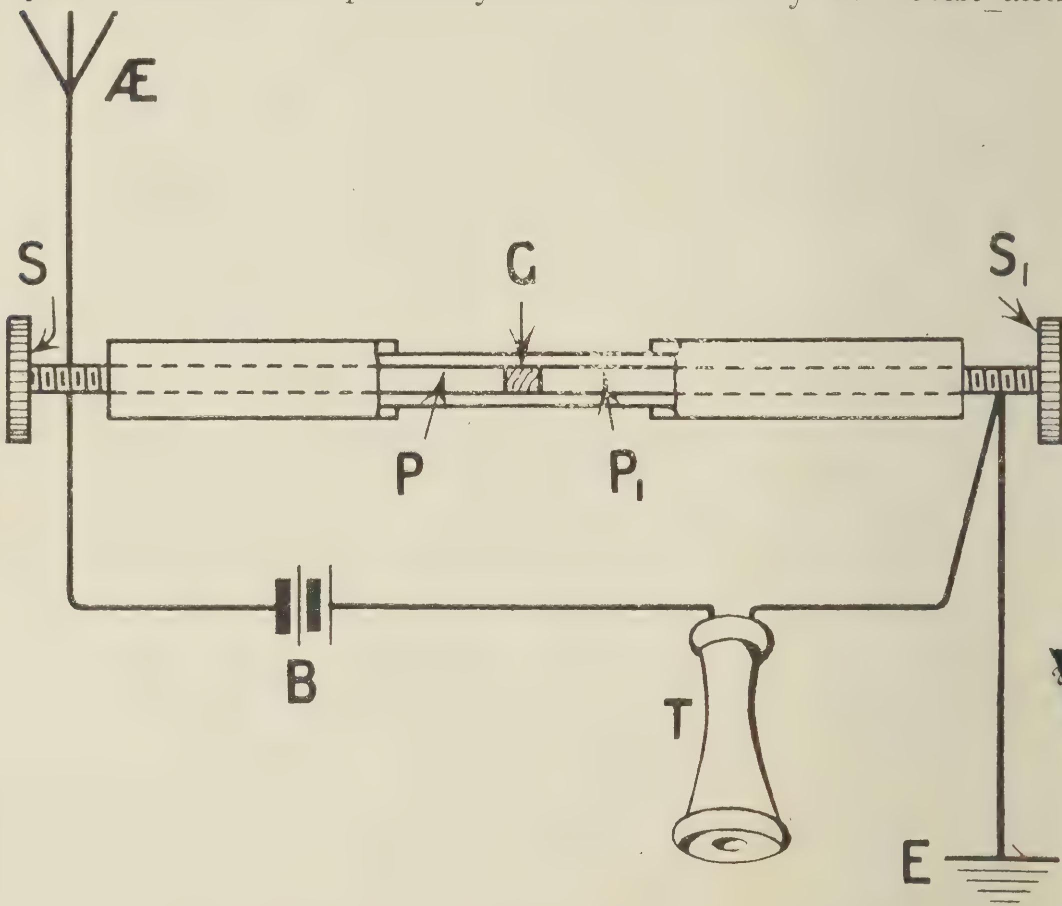


FIG. 48. Diagrammatic representation of Lee de Forest's "Responder." The space G is filled with a paste of lead oxide, metallic filings, glycerine, and water.

Smythe, and known as de Forest's "Responder" (27), (92). This detector, which is of the anti-coherer type, was used extensively in Dr. Lee de Forest's wireless system during the Russo-Japanese War. It consists (see Fig. 48) of a tube fitted with two metallic electrodes P, P_1, the distance between which (about 0.01 inch) is adjustable by means of set screws S and S_1.

The connections to earth and aerial are as shown. The telephones are connected in series, with a few cells, across the detector.

In the space between the electrodes P, P_1 is placed a small quantity of "GOO." This is the inventor's name for an electrolysable paste of lead oxide (litharge), glycerine, and water, and some metallic filings. Under the action of the constant current from the battery B the well-known crystalline structures are formed known as "lead trees." These tree-like outgrowths are partially destroyed by the received oscillations, and are instantly restored again by the constant current. Before using this detector, in order to adjust its sensitivity, the ends of the electrodes are first brought tightly together within the tube and then slowly separated, until, by repeated trials, the right adjustment is found.

THE POSITIVE POINT ELECTROLYTIC DETECTOR.—Another form of electrolytic detector was invented in 1900, independently, by **Ferrié, Fessenden,** and **Vreeland** (it is interesting to note that the electrolytic break for induction coils was invented by **Wehnelt** in 1899). In design this detector takes the form of a miniature Wehnelt break.

It consists of a fine point of platinum wire about one thousandth of an inch in diameter, forming the positive electrode. This dips into a solution of dilute sulphuric or nitric acid, in a small lead cup, which forms the negative electrode. This is placed in series with a pair of high-resistance phones and a potentiometer.

In another form, instead of employing a bare length of fine platinum wire, the wire is first sealed in a short length of glass tube, drawn out to a point. It is broken off short at the glass, and the tube is then placed in the acid, contact being made with the sealed platinum point by means of a little drop of mercury, placed in the tube into which the connection wire dips.

It is often advisable to grind down the glass point, so as to expose the extreme tip of the platinum wire to its best advantage. This can be done on an ordinary oil stone. M. Child was among the first in this country to use an electrolytic detector of this type.

In 1903 **W. Schloemilch** (326) took out an American patent for a similar electrolytic detector, the difference being that by the employment of a suitable electrode (such as zinc) in the little cell containing the acid he generated the current to energize the receiver, thus obviating the necessity of em-

ploying a separate battery and potentiometer. This detector never became popular.

Similar detectors were evolved by **Shoemaker** (85) and **Reich**, the latter being employed by the Telefunken Co. (92).*

In 1904 **Fessenden** (328) applied for a patent for two forms of electrolytic detector, shown in Fig. 49, in which either the

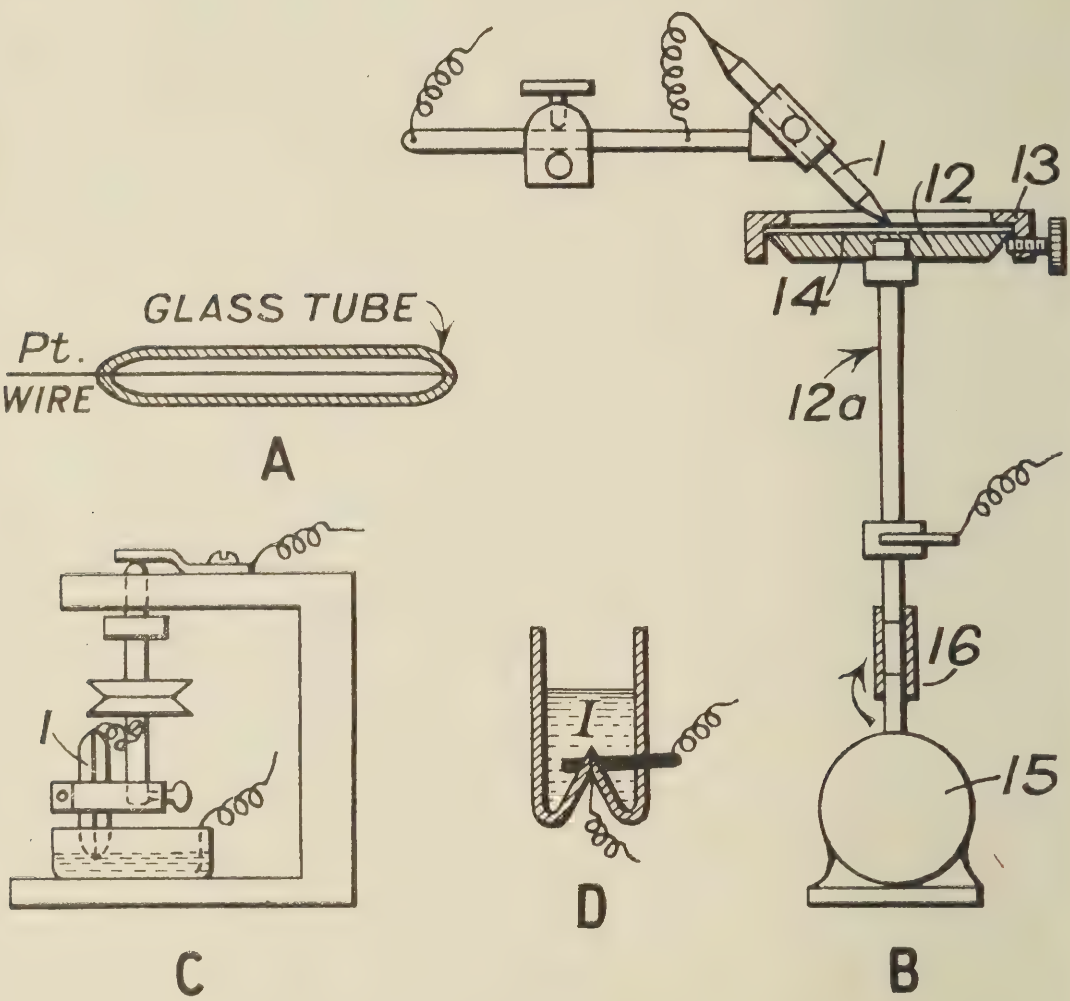


FIG. 49. Details of several forms of Fessenden's electrolytic detector.

platinum point or the electrolyte was rotated. The following is a brief abstract of this patent (329):

Fig. 49a shows a small glass tube with a platinum

* *The Human Body as a Detector* (220).—In 1924 **J. Strachan** showed that if the crystal detector was removed from a wireless set, located in proximity to a powerful broadcasting station, portions of the human body could be substituted for the crystal, one contact being firmly made and the other being very slight. As he was able to obtain a similar result by means of a slight contact with a solution of salt water, he concluded that the effect was an electrolytic one.

wire 0.0005 of an inch sealed into the ends and one end ground flush with the glass, so that the wire is exposed only on its end surface. The ground-off tip, or terminal, of the electrode terminal I is arranged adjacent to a disc 12 (Fig. 49b) of conducting material (preferably of brass), the tip itself resting on a moisture retaining covering 14. The covering is composed of an inner layer of absorbent material, and an outer layer of soft material such as cotton velvet, and is held in position by the clamping ring 13.

"The disc 12 is mounted upon a shaft 12a, driven by clockwork 15 through an intermediate rubber coupling 16, to prevent the transmission of vibration or shock from the clockwork to the disc.

As an alternative, the glass tube containing the sealed electrode terminal may be mounted upon an arm on a vertical

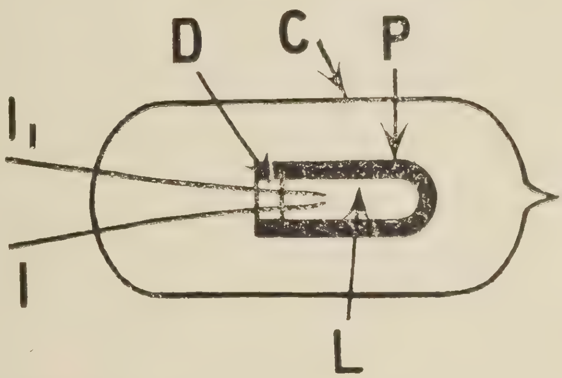


Fig. 50. A detecting device invented by Fessenden, depending for its action on the changes in resistance of a short and extremely fine platinum wire.

rod and revolved in a bath of solution, so that here again the friction of the liquid against the exposed terminal will remove any gas which may form thereon, as shown in Fig. 49c.

Fig. 49d shows a vertical section of another form of such a cell, where the electrode I is embedded in the glass bottom of the cell and ground off so as to be practically flush with the surface.

Thus, a minute cross section of liquid makes contact with the ground-off cross section of the end of the conducting electrode.

Fessenden's Barreter.—In 1902 Fessenden took out an American patent (No. 706742) and a British patent (No. 17705, August 12th, 1902), in which he describes "a current-actuated wave-responsive device, consisting of a conductor having a small heat capacity and arranged in a vacuum." It is shown in Fig. 50.

$I I_1$ is a continuous length of silver wire, having a diameter of 0.002in., having a platinum core of 0.00006in. in diameter. The extreme tip of the loop is immersed in nitric acid until all the silver has been dissolved, leaving a minute length of platinum (a few thousandths of an inch) exposed. The leading-in wires (I and I_1) are sealed into a glass bulb C and into the glass top D of a silver shell P and the bulb is then exhausted.

The heat capacity is so small that an infinitesimal amount of energy is sufficient to heat it very quickly, and it is equally capable of extremely rapid cooling, so that exceedingly rapid changes in its electrical resistance occur under the action of received oscillations. This instrument is usually employed in conjunction with a Wheatstone Bridge.

In 1906 **Lieutenant C. Tissot,** of the French Navy, invented a Bolometric method for the measurement of the received current in Wireless Telegraphy, a full account of which appeared in the Journal of the Institution of Electrical Engineers of the same year.

WALTER'S TANTALUM DETECTOR.—In 1907 **L. H. Walter** (853) showed that an oxidised tantalum wire, just touching the surface of a globule of mercury, made a sensitive detector.

SYDNEY G. BROWN'S PEROXIDE OF LEAD DETECTOR.—In 1904 **S. G. Brown** patented a detector (330) which consists of a pellet of an electrically-deposited peroxide of lead (as used for the plates of accumulators) between a platinum plate and a blunt lead point. The latter is attached to the end of a steel spring, and its pressure upon the peroxide can be adjusted. This detector works best in series with a two-volt battery and telephone, the platinum being connected to the positive terminal of the battery. It has been used satisfactorily to operate a "siphon" recorder directly (without the employment of any relay) (28).

WICHI TORIKATA'S DETECTOR.—In 1908, in Japan, **Wichi Torikata** patented a detector (337) in which a tantalum point dips into some alkaline or acid solution (patented in U.S.A. 1913). This was fully illustrated and described in "The Electrician" in 1910 (30). In this article Torikata claims that this detector is extremely sensitive, and has a long life, as the tantalum is not acted upon by the acid or alkali which he employed.

C. V. Boys' Bouncing Jet Detector.—This detector, which was patented in 1905 (839), is comparatively insensitive. It is based upon a phenomenon of surface tension investigated by **Rayleigh** (92), and known as the experiment of the "bouncing jets." If two fine jets of acidulated water are arranged to impinge at an acute angle, they usually rebound, and do not coalesce. A very small voltage applied between them causes them to combine. This effect has been employed to work a mechanism for wireless reception.

CRYSTAL DETECTORS

Ferdinand Braun, in the year 1874, showed that the electrical conductivity of several metallic sulphides differed according to the direction in which the current passed through them, *i.e.* that their resistance depended on the direction of the current as well as its intensity. Amongst other substances which he investigated for this effect were galena and copper pyrites (324).

General H. H. C. Dunwoody, of the U.S. Army, discovered that carborundum acted as a rectifier, and he showed that when employed in conjunction with a potentiometer it could be used in the place of an electrolytic detector. This he covered by U.S. patents, on Dec. 4th, 1906.* As shown by **W. H. Eccles** and others, the best type of carborundum for use as a carborundum detector is that which is composed of crystals silver-grey in colour—the highly-coloured crystals are far less sensitive. In Germany, **Braun** carried out extensive investigations on various crystals.

Carborundum-Mercury Detector.—In 1914 **J. Kuhr** and **A. W. Bridges** patented a detector (218) consisting of a carborundum crystal immersed in mercury.

Wichi Torikata's Crystal Investigations.—In Japan, **Wichi Torikata** (30) investigated about 200 kinds of minerals, and found that zincite, molybdenite, pyrolusite, iron pyrites, cassiterite, galena, etc., were all sensitive as Wireless detectors, and in 1908 he was granted a Japanese patent (338) for his Koseki, or mineral detector. This patent covers the employment of these minerals, which he considered the best. Afterwards, with **E. Yokoyama**, he systematically tested all the mineral samples in the Mineral College of the Tokyo

* For English Patent see Ref. (859).

Imperial University. The following is abstracted from his excellent paper in "The Electrician" of September 16th, 1910:

"We found that the following ores are quite responsive to electric waves; 1. Ores quite sensitive with perfect contact—

(*a*) Oxides.

Simple Oxides.

Zincite.
Tenorite or Melaconite.
Cassiterite.
Anatase.
Arkansite.
Pyrolusite.
Wad.

Complex Oxides.

Micacious hæmatite.
Ilmenite, Iserine, Hystatite.
Magnetite.
Psilomelane.

(*b*) Sulphides.

Simple Sulphides.

Molybdenite.
Galena.
Zinc-blende.
Chalcosine.
Iron pyrites.
Pyrrhotine.

Complex Sulphides.

Nagyagite.
Tennantite.
Enargite.
Boulangerite.
Schwatzite.

(*c*) Metallic Combinations.

Lollingite.
Meteorite.
Smaltite.

2. Ores sensitive with a light contact—

(*a*) Sulphides.

Simple Sulphides.

Marcasite or Kyrosite.
Covelline.

Complex Sulphides.

Siegenite.
Copper pyrites.
Cobaltite.
Ullmanite.
Bornite.
Sylvanite.
Arsenical pyrites.

(*b*) Metallic Combinations.

Nicolite.
Domeykite.
Strutterudite.
Allemontite.
Iridosmine.

(*c*) Native Elements.

Graphite.
Arsenic.

"Nearly all ores with good conductivity can be used as a detector; but some of them require very light contact and delicate adjustment, and are not practicable. The action of mineral detectors seems to depend upon the chemical and physical properties of the ores and also upon the condition of the contacts, but not upon the crystalline structure and axis of the ores. Generally, the resistance of copper pyrites is very low, and that of zinc-blende is very high, and they cannot be used as practical detectors when they are inserted alone between two metal poles; but their well-tarnished surface acts as a very sensitive detector. The zincite which I got at first was a fine hexagonal crystal. I tested the sensitivity of the zincite by various methods, but could not find any difference depending on the axis of the crystal.

"Every ore was tested in contact with a number of other ores as well as metals. Molybdenite does not give so distinct a result; but zincite gives a marked effect according to the ore in contact with it. Generally speaking, crystals which conduct electricity and heat very well seem to give better results than metals or other ores. Bornite, copper pyrites, or iron pyrites give excellent results when in contact with molybdenite or zincite, especially with the latter. Copper pyrites and bornite are nearly equally good, but we always get better results with bornite. Bornite alone cannot be used as a detector, but when used with other minerals or crystals it greatly increases the sensitivity. **Mr. Saiki** has devised the use of bornite with carborundum. The carborundum detector, which was invented by General Dunwoody, is very sensitive when used in contact with metals or carbon, but it is further improved by the use of bornite."

"Molybdenite or iron pyrites make a very sensitive and practicable detector when merely brought in contact with a metal point, such as platinum, steel, brass, etc."

PICKARD'S "PERIKON" DETECTOR.—In the United States, **Greenleaf W. Pickard** invented a detector, the original "Perikon" Detector, for which he procured a registered trade mark, No. 70,587. It consisted of a brass point resting on the surface (either rough or polished) of a piece of silicon (U.S. patent No. 886,154). This same name, "Perikon," is now used for the detector with zincite and chalcopyrite patented by Pickard in the United States in 1909 (336), (124), (92), (854), (870).

LYON'S CERUSITE DETECTOR.—In 1911 **Thompson H. Lyon** patented a detector in U.S.A. (341) in which he claimed the use of "Cerusite" ($PbCO_3$) as a rectifier in place of silicon.

PIERCE'S MOLYBDENUM DETECTOR.—**Pierce** has described a detector consisting of a copper point against sulphide of molybdenum.

THE BRONC CELL.—A very favourite detector in Germany. At one time it was known as the "Bronc" cell; consisted of a finely-adjusted contact between tellurium and graphite.

AUSTIN'S DETECTOR.—**L. W. Austin** filed a patent in 1906 for a detector consisting of a contact under slight pressure between a short roller of silicon and a block of tellurium, which acted as a thermo-couple (857). In a later patent he covered the use of a contact between aluminium and tellurium (858).

THE LEPEL COMPANY'S DETECTOR.—The Lepel Company employed a galena-plumbago (pencil lead) detector at their Whitton Station (near Twickenham) just before the Great War. The author recalls an experiment shown to him by

Mr. Marchant, who was then in charge of that station, by which he showed that this form of detector was not only sensitive to the received high-frequency oscillations, but was also sensitive to heat radiations.* When a match was struck in the vicinity of this detector a sound was distinctly audible in the phones.

Lepel's Compressed Dialectric Detector.—In 1906 **E. von Lepel** patented a detector (846) which consisted of two electrodes, one flat and the other spherical, separated by india-rubber, collodion, or celluloid, the electrodes being forced together by a pressure applied by a thumbscrew. When under a stress of some three hundredweight the insulating material between them allows a current to pass.

Iron Sulphide Detector.—In 1907 the **Author** found that a contact between iron sulphide (FeS) and steel or iron made an excellent detector (334) and (335). This was particularly the case with some samples of home manufacture, made by melting sulphur and iron filings together in a closed crucible.

Donle's Vacuum Tube Crystal Detector.—In 1923 **H. P. Donle** patented a crystal detector. He placed the crystal in an evacuated tube to protect it from oxidation and dust (721).

Dr. Eccles' Investigations (Detector Curves and Oscillating Crystals.)—Between 1909 and 1911 **Eccles** investigated many kinds of detectors—crystal, electrolytic, and magnetic—published their characteristic curves, and gave theories of their action. He discovered that the detector formed by a galena-galena contact, which he was probably the first to use, could behave like a " Duddell arc," and produce oscillations. In 1909 he invented a microphonic relay, which he used for the production of audible oscillations of small amplitude.

Other Investigations: (613 & 708)

Oscillating Crystals for Reception and Transmission (832), (834), (1029).—In Russia, **O. V. Lossev**, employing a steel and zincite contact, has not only received C.W. signals, but has also used an oscillating crystal contact to transmit C.W. signals over very short distances.

* In the light of the modern discovery of the photo-electric properties of certain contacts it is probable that this effect was due rather to light than to heat.

In England, **J. Scott-Taggart** (832) has employed similar connections to those used for an "oscillatory arc,"* *i.e.* a high-tension supply (of from 15 to 20 volts) was used, with a series resistance and air chokes in the leads to the crystal and steel contact, which took the place of the usual arc electrodes. An inductance and condenser in series were shunted across the latter to form the oscillating circuit. With this arrangement he was able to obtain radio-frequency oscillations, which he employed to heterodyne C.W. signals (834). Reference

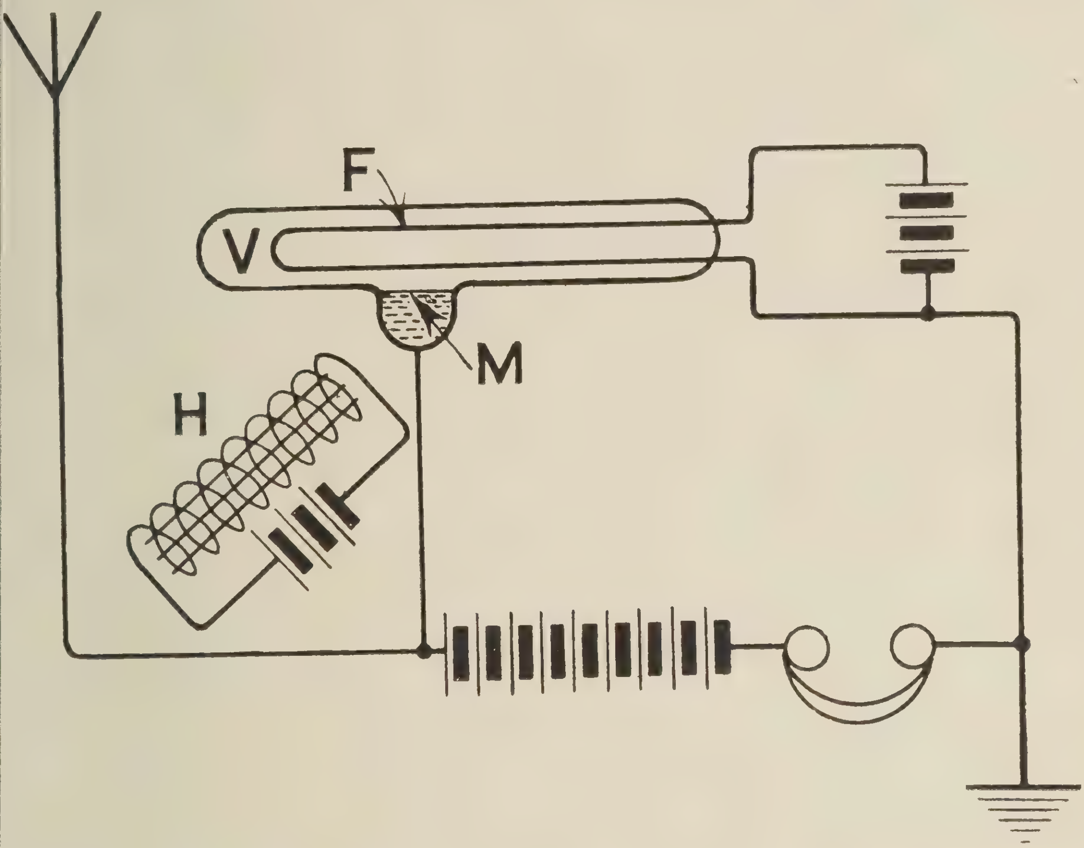


FIG. 51. A gas-filled tube V with a pool of mercury M, and a heated filament F electrode, forms the molecular detector patented by Lee de Forest.

should also be made to the work of **I. Podliasky** on oscillating crystals (1025), (1072).

OTHER FORMS OF DETECTOR

DE FOREST'S MOLECULAR DETECTOR.—In 1906 **Lee de Forest** patented a molecular detector (see Fig. 51) which consisted of a gas-filled vessel V the gas in which was (according to the description given in the patent specification (852) kept in a state of molecular activity by means of a heated filament F

* Note the use of crystals for arc electrodes in the T.Y.K. system in 1912. See Chapter XI. of this book.

arranged above a pool of mercury M, the regulation of the detector being controlled by a magnet H.

Heated Thermo-Couple Detector.—The German Wireless Telegraph Company (863) patented a thermal detector in 1906 consisting of an oxidized copper plate heated in a flame, and in contact with an aluminium or platinum wire. The pressure of the contact is adjustable.

The heat of the flame generates an E.M.F., which is passed through the receiving instruments. The effect of the received waves is to vary this current.

Another form patented by this Company (863) consists of a loose contact between a heated oxidized copper plate and a lead electrode. In this case the heating of the thermo element is adjusted to balance the auxiliary current, and the received oscillations destroy the balance.

Hot Point Detector.—In 1924 the **Author** (1021), (1084) carried out some experiments with various crystals in contact with a heated platinum or German-silver point, and found that signal strength perceptibly increased with a slight rise in temperature, but that no signals were obtainable when the point reached red heat. The point consisted of a sharp bend or loop of wire which was heated by an accumulator, the heat being controlled by resistances.

Latour's Glow-Lamp Detector.—In 1916 **M. C. A. Latour** (997) invented a photographic method of recording signals after valve amplification. For this purpose he placed a small electric lamp having a very fine filament in the secondary circuit of a transformer, the primary being in the plate circuit of the last valve. The lamp was maintained at a temperature just below incandescence by means of a local battery in the secondary circuit, or by means of a local source of oscillations of the same frequency as the received waves. The flickering light of the lamp due to the signals was recorded on a moving photographic strip.

The N.V.N. Thermal Detector.—In 1917 The Naamlooze Vennootschap de Nederlandsche Thermo-telephoon Maatschappij patented a method of reception (983) in which a thermic telephone is employed shunted by a condenser in a tuned receiving circuit. The telephone is heated by means of a local battery included in the circuit, in addition to the heat produced in it by the received signals. A similar

idea was patented by **Townsend** in 1918 (984). In this case a small incandescent filament electric lamp is used as detector. This is kept at a heat just below incandescence by a local battery, and made to glow by the received oscillations. It is primarily intended for use in a wavemeter.

Claude's Neon Detector (885) (see also "Use of Neon Tubes" in Chapter XVI.).—This detector, invented by **G. Claude** in 1914, consists of two electrodes about two millimetres apart in a vacuum tube containing a trace of neon. The tube is placed in the aerial circuit in series with a high-tension battery supplying a voltage almost sufficient to start a current through it.

Fessenden's Frictional Receivers.—Patented in U.S.A. in 1913 (344), (92). In this invention the waves are caused to produce a direct mechanical effect by their action on moving bodies in tractional or frictional relation, and to vary such relation, *i.e.* to vary the amount of friction. The following is a quotation from the Patent Specification :

"My invention, therefore, involves at least two conductors, one of them preferably a solid, arranged to develop frictional or other tractional stress with or without contact of the parts transmitting or tending to transmit motion ; the modification of such stress by the electro-magnetic wave, and, finally, the utilization of the change of stress directly or indirectly to produce a signal or indication. . . . I prefer to develop said stress between relatively moving bodies between which there is a frictional effect causing one of them to tend to move the other, such tendency being opposed and partially counterbalanced by stress in the opposite direction. . . . In most cases I prefer to arrange matters so that the total amount of friction will be increased by effecting an increase in the value of the factor known as the coefficient of friction, or the pressure of the magnetic friction."

Fig. 52a shows one form of instrument in which the frictional stress is developed between a rotating wheel (1) driven by clockwork or by a suitable motor and a body (2) resting against (1) and tending to follow the direction of movement of the latter but restrained by the diaphragm (3) with which it is connected. This diaphragm is preferably very thin, and correspondingly delicate.

The rotating wheel (1) may be made of silver, nickel, 10 per cent. bismuth-gold alloy, or other suitable material, and the body (2) may be a piece of thin gold leaf or amalgamated copper foil. The receiver is inserted in any desired receiving circuit by connecting the body (2) to the aerial (4) and the wheel to the earth (5). On the arrival of a signal the frictional force between (1) and (2) is increased, so causing

the diaphragm (3) to be vibrated. Another form of the device is shown in Fig. 52b. Fessenden used milk as a lubricant between the rotating wheel and the gold leaf.

THE TIKKER (or "Ticker").—This is a form of detector employed by the Poulsen Company at the receiving station to interrupt the received C.W. signals (which arrive at a frequency above audition) and to cut them up into a series of groups of high-frequency oscillations, the interruptions occurring at an audible frequency. These detectors have

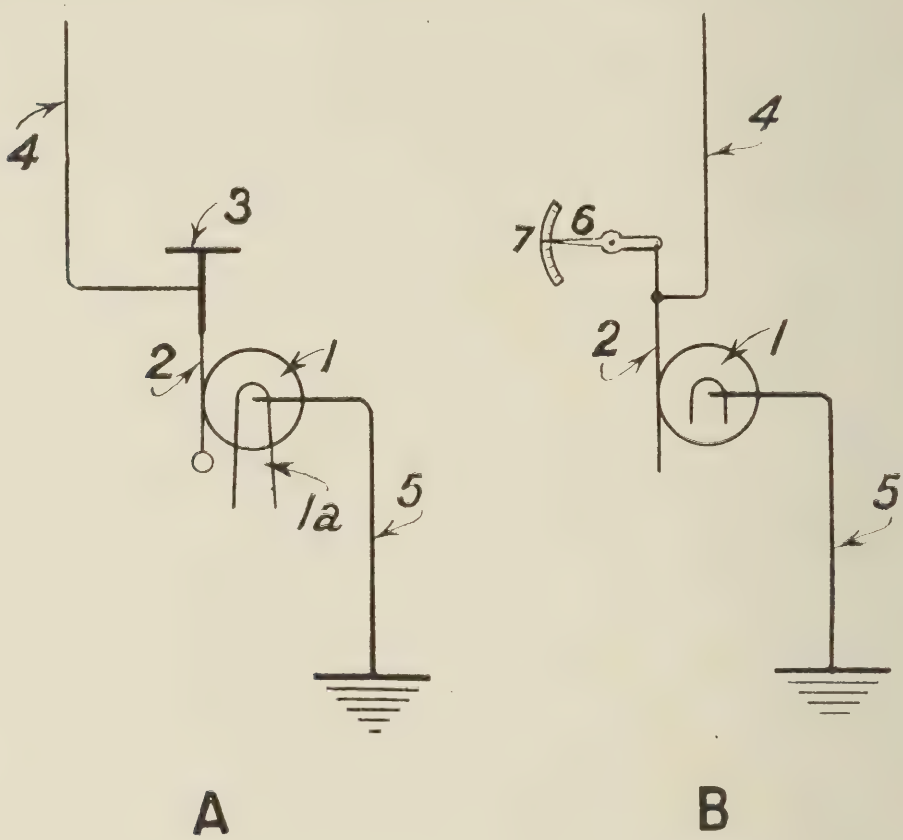


FIG. 52. Two forms of Fessenden's frictional detectors in which use is made of the fact that incoming oscillations change the frictional forces between two moving bodies in light contact.

proved to be at least as sensitive as any type of crystal or electrolytic detector. The design, illustrated in Fig. 53 and Fig. 54, is due to **P. O. Pederson** (92), (378), (379), and patented by him in 1906. (See also references (855), (856).)

The use of an interrupter in the receiving circuit was previously proposed by **Tesla** (371) and covered by his British patent No. 11,293 of 1901 (370), (372).

The "Poulsen" Tikker, consists, as shown in the diagram Fig. 54, of a small reed vibrated by magnetic action, similar

to that of an electric bell. On the end of this reed, and insulated from it, is a gold wire, which vibrates against a second gold wire and so acts as an interrupter to the telephone circuit.

Fig. 53 is a diagram of connections. O is a condenser about 0.01 micro-Farad capacity, T the telephone, K the two vibrating contacts of the Tikker, C_2 variable condenser, and L_2 the closed circuit inductance. Its action is as follows: Suppose the open circuit Æ, L_1, E of the station to be attuned to incoming C.W. signals, and the contacts of the Tikker K to be separated when the closed circuit L_2, C_2 is brought into tune, the oscillations in the latter build up and energy

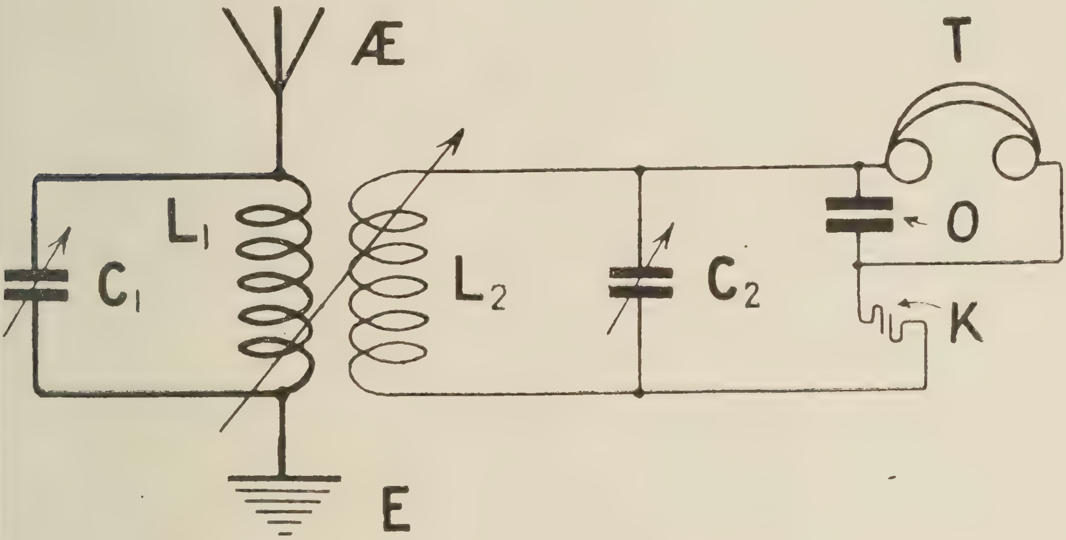


FIG. 53. A suitable receiving circuit for use with the Poulsen Tikker.

is stored in the variable condenser C_2. Directly the contacts of the Tikker K touch one another the variable condenser is discharged, and the whole or part of the energy passes into the condenser O. This condenser is large, and has not time to discharge before the Tikker again interrupts the circuit and leaves the charge on O free to leak away through the phones T. There being no prearranged agreement in frequency between the Tikker vibrations and the received oscillations, the current through the telephone is erratic, both as regards magnitude of current and direction, according to the phase of the oscillation at the moment the contacts close. This irregularity of action produces a buzzing in the telephone, and not the same musical note which is emitted by the vibrating reed of the Tikker.

THE ROTARY TIKKER (92).—This is another form of Tikker employed in the Federal Poulsen system. It is very sensitive, and is an efficient detector of either damped wave trains or undamped oscillations. Its invention is attributed to **L. W. Austin.** It may be connected in circuit in exactly the same way as any crystal detector for Morse reception, and is shown in Fig. 55.

D is a revolving brass disc upon the brightly polished edge

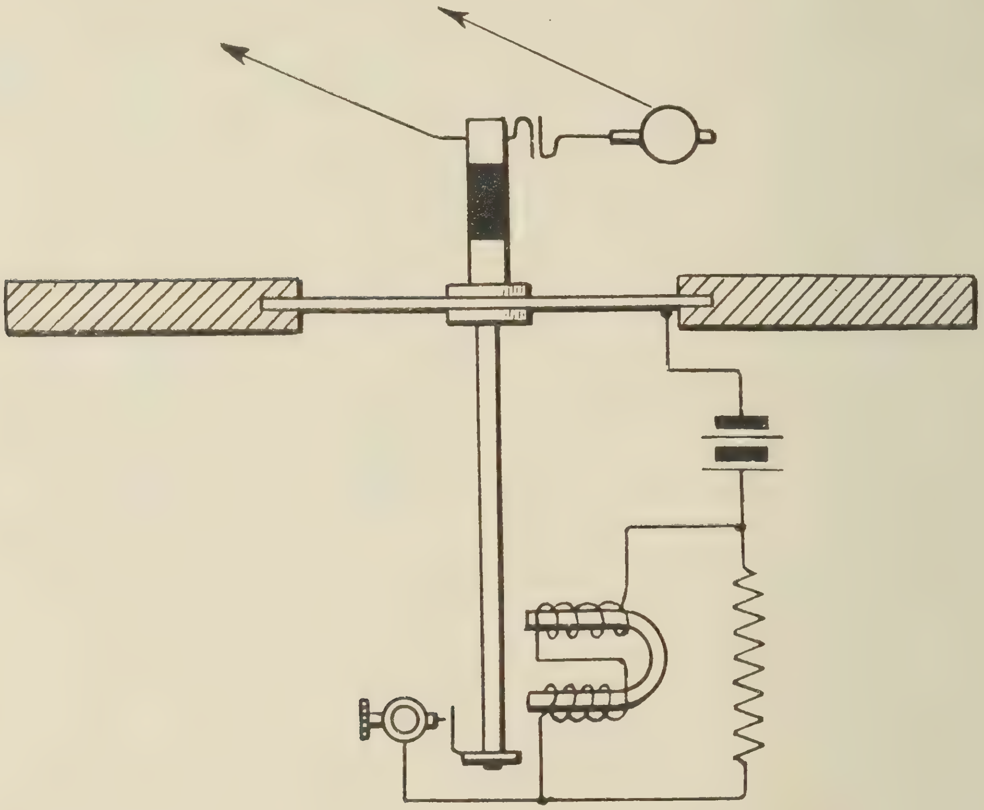


FIG. 54. The Poulsen Tikker shown in diagrammatic form.

of which rests lightly a fine steel wire T (many other metals besides brass and steel may be employed). Both the edges of the disc and the wire must be kept absolutely clean and free from any form of grease. The wire should not be over one inch in length. Connections are made by means of a brush B and the wire holder H. The small auxiliary wheel or groove against which the brush B rubs may be kept lubricated.

GOLDSCHMIDT'S TONE WHEEL (92).—This is another form of C.W. detector of the rotary type. It is very similar to that of Austin, but a rotating commutator with brushes, or a toothed disc, is employed to interrupt the H.F. currents and produce a definite "tone" in the phones.

This detector has been successfully employed in transatlantic communication.

Gas Flame Tikker (353).—This device is illustrated in Fig. 56. It consists of a spiral of platinum wire S arranged above a fine gas jet F. After the gas jet has been lighted, a length of glass tube G, about one inch in diameter and 19 inches long, is slipped over it, and the gas is then turned down until a high piercing note is emitted. (At this stage, if the flame is viewed in a revolving mirror, it is seen that the note is due to a series of explosions occurring in rapid succession above the flame.)

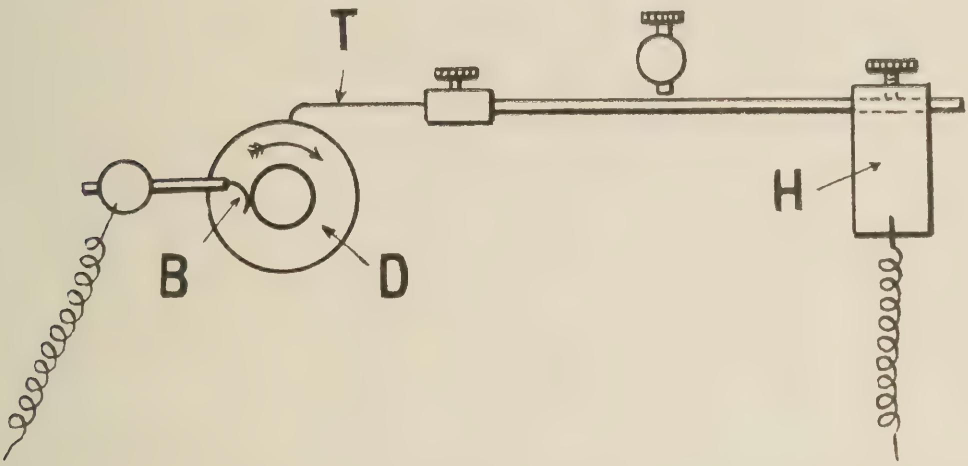


Fig. 55. A form of interrupter which depends for its action on the frictional contact between a fine wire T and a metal disc D.

The flame completes the circuit it is desired to interrupt, connection being made to the gas tube P and to a spiral of platinum wire S at the top of the flame.

Goldsmith's Varying Mutual Inductance Method of C.W. Reception.—In 1919 **A. N. Goldsmith** assigned to the Marconi Company (998) a method of reception in which continuous wave signals are broken up at the receiving station by periodically varying the mutual inductance between coupling coils in the receiving circuits.

Several methods were shown. One was to place intermittently a conducting plate between the coupling coils, *e.g.* projecting teeth on the circumference of a rotating wheel.

Another method was intermittently to short circuit a coil of wire placed in a fixed position between the two coupling

coils, *i.e.* the aerial tuning coil and the closed circuit inductance coil.

Goldsmith also devised a similar method of varying the

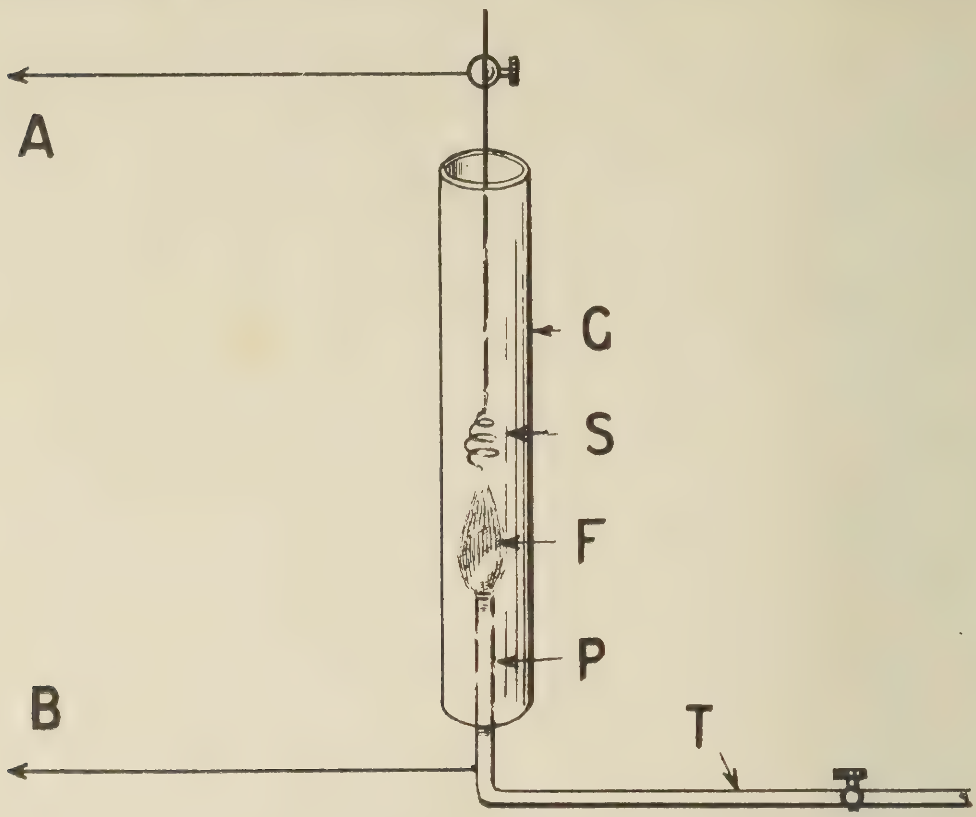


FIG. 56. In this form of Tikker the interruptions are provided by a series of successive " explosions " of gas in a tube.

inductance of a coil or coils when tuning, or for altering the coupling between circuits, by the movement of a copper cylinder axially with respect to the coils, or by means of a flat metal disc which is slid across one end of the coil (999).

CHAPTER VIII.

THE DAWN OF PRACTICAL RADIO-TELEGRAPHY (160) and (161).

IN order to classify the various types of Magnetic Detector, and group them together for convenient reference, we were obliged, in the last chapter, to depart somewhat from the sequence of our history. We will now revert to the year 1889, which marked a new era.

In this year, two years after his election as a Fellow of the Royal Society, **Dr. Lodge**, metaphorically speaking, sowed the seed from which syntonized or tuned Radio-telegraphy has grown (34). Lodge discovered that if two circuits were so arranged that the product of the capacity and the inductance

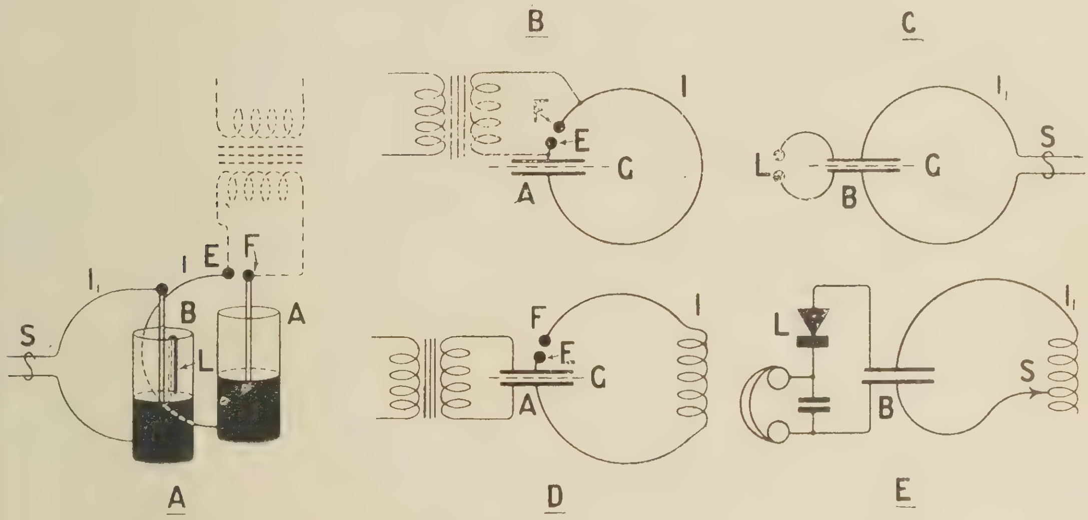


FIG. 57. Illustrating Lodge's experiments with his Syntonic Jars, and the evolution of tuned circuits in radio.

of one equalled that of the other he could obtain an electrical resonance effect corresponding to the resonance of two tuning forks having an equal frequency of vibration.

LODGE'S SYNTONIC JARS.—Fig. 57A is a diagram representing Lodge's now so well-known experiment of "Syntonic Jars" (160). Two Leyden Jars of similar electrical capacity, A and B, are placed near to one another on a sheet of glass or other insulator. A loop of wire I ending in a spark knob E leads from the outer coating of jar A to a knob F connected to the inner coating of the jar. These two knobs are separated so as to form a spark gap, and connected to the secondary of a small induction coil. The second Leyden Jar, B, is fitted with a similar loop of wire I_1 connected directly to its outer

and inner coatings. The length of this loop can be varied by means of a little slider S. A strip of tin foil L, connected to the inner coating, is pasted to the jar, and leads right over the glass of the jar till it almost touches the outer coating, forming a very minute spark gap. When the induction coil is switched on jar A charges and discharges across spark-gap EF, emitting short Hertzian waves.

The B circuit can, by careful adjustment of the slider S, be tuned to the same frequency of oscillation, and when so tuned, and only then, sparks occur across the little gap between L and its outer coating. **Sir Oliver Lodge** said, speaking of this experiment, "A closed circuit such as this is a feeble radiator, and a feeble absorber, so it is not adapted to action at a distance. In fact, I doubt whether it will visibly act at a range beyond $\frac{1}{4}\lambda$, at which true radiation of broken-off energy occurs."

"If the coatings of the jar are separated to a greater distance, so that the dielectric is more exposed, it radiates better, because in true radiation the electro-static and the magnetic energy are equal; whereas, in a ring circuit, the magnetic energy greatly predominates. By separating the coats of the jar as far as possible we get a typical Hertz vibrator (see Fig. 32A), whose dielectric extends out into the room and thus radiates very powerfully."

Lodge later employed his syntonic jar method of tuning in conjunction with his original "Two-sphere" coherer (of 1889) and an electric bell.

Fig. 57 (B, C, D, and E) shows how our modern tuning circuits have been developed from the Lodge Syntonic Jar experiment. B shows a transmitter, where the jar A has been replaced by a flat condenser A (a sheet of glass G coated on either side with metal foil). C shows a receiving circuit, with a similar flat condenser B, the received oscillations being rendered visible by a small spark-gap L. D shows the obvious development for the production of longer waves, the inductance of the circuit being increased by the introduction of an inductance coil I.

E shows the equivalent development of a receiving circuit and the displacement of the spark gap by a crystal detector and phones.

MARCONI'S 1897 METHOD OF TUNING.—**Marconi,** in his patent of March 2nd, 1897, adopts a kind of rough and ready

method of tuning by means of metal strips or plates on either side of his coherer, very similar to the resonator of Hertz.

The following is a quotation from the patent referred to, in which he says: " The means I adopt for fixing the proper length of the plates is as follows: I stick a rectangular strip of tin foil about 20 inches long (the length depends on the supposed length of the wave that one is measuring), by means of a weak solution of gum, on to a glass plate; then, by means of a sharp penknife or point and ruler, I cut across the middle of the foil, leaving a mark of division M^2. If this glass plate is held a few feet away from the origin of the electrical disturbances, and in such a position that the strips of tin foil are about parallel to the line joining the centre of two spheres in the transmittng apparatus, sparks will jump from one strip to the other at M^2."

"When the length of the strips of foil has been so adjusted as to approximate to the length of the wave emitted from the oscillator, the sparking will occur at a greater distance from the oscillator when the strips are of suitable length. By shortening or lengthening the strips, therefore, it is easy to find the length most appropriate to the length of wave emitted by the oscillation producer. The length so found is the proper length for the plates, or, rather, these should be about half-an-inch shorter, on account of the length of the sensitive tube (coherer) connected between them."*

LODGE'S 1897 METHOD OF TUNING.—On May 10th, 1897, **Lodge** took out a patent, No. 11,575, entitled " Improvements in syntonized telegraphy without wires," based directly on his work before referred to. His transmitting and receiving antennae consisted of large cones of sheet metal, placed one above the other in a vertical line, as shown in Fig. 58A.

A and B are the two transmitting cones, and C and D those at the receiving station. These " capacity areas " and the inductance coils C and C_2 are exactly alike at the two stations, so that each station has exactly the same frequency of electrical vibration.

Fig. 58B shows the transmitting connections devised by Lodge for use with his " capacity areas."

* In 1898 Marconi employed " Jiggers " and tuned his coherer circuits (28) See also the Marconi Multiple tuner, page 124.

The outer coatings of two Leyden Jars J and J_1 are connected together through an inductance coil I wound with fine wire, which serves as a choke. The jars are charged by means of an induction coil K, and discharged at a spark-gap G. The induced charges on their outer coatings charge up the "capacity areas" A and B across gaps G_1 and G_2, the object of which is to leave the oscillating circuit A, C, S, C_1, B

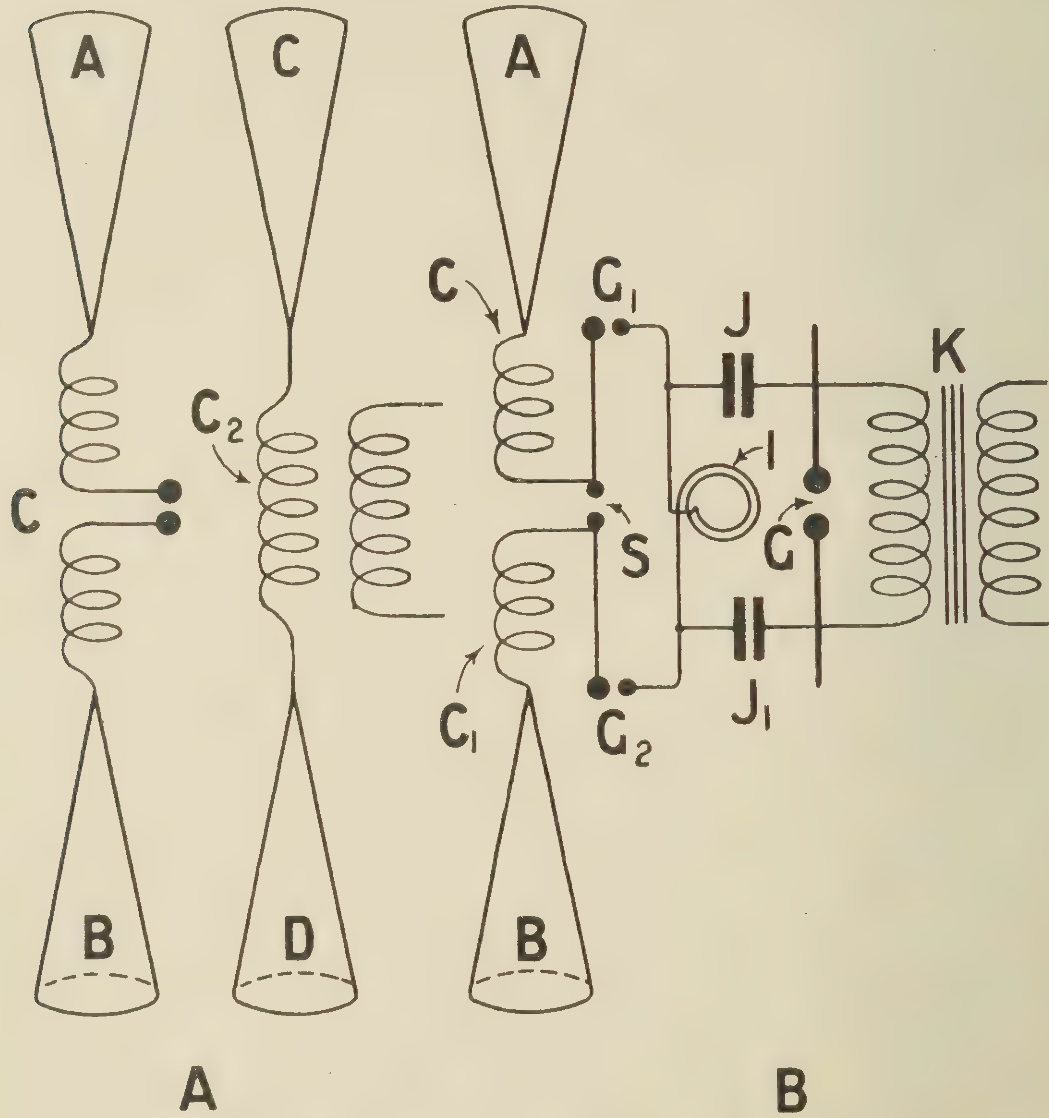


FIG. 58. Shows Lodge's use of sheet metal cones as aerials for transmission and reception

free to oscillate, when a state of oscillation has been set up therein by the charge from the capacity areas discharging across gap S. In the original design the capacity areas were placed in a vertical position, both being elevated above the earth and insulated therefrom.

Lodge later used a flat network of wires overhead, a wire from the centre of which led through the inductance, etc.,

to a similar counter-capacity or network of wires stretched below it, but also insulated from the ground (see Fig. 59).

LODGE'S INDUCTIVE COUPLING.—**Lodge** also inductively coupled his instruments to the aerial system, placing them in a separately-tuned secondary circuit. This most important arrangement was covered by his patent No. 18644, 1897 (see Fig. 59).

Lodge's patents were extended in 1911 for seven years, and acquired by the Marconi Company from the Lodge-Muirhead Syndicate. Their validity was subsequently contested before Lord Moulton; but, says Lodge, "were triumphantly upheld, after twelve days' trial, as containing the necessary and fundamental principle of all tuned wireless not involving

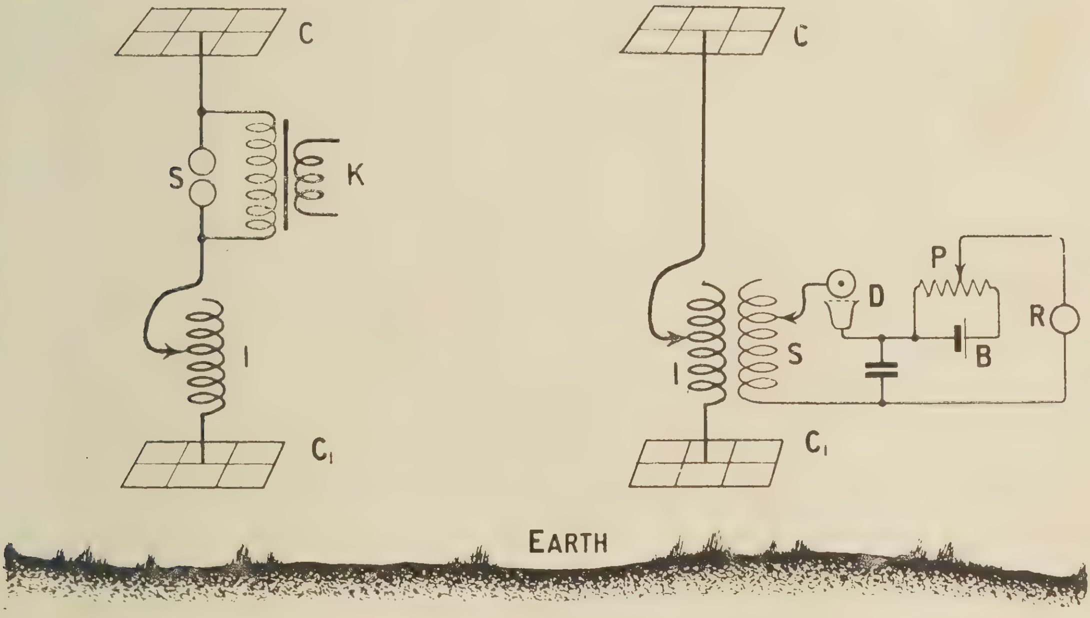


FIG. 59. Arrangements similar to the modern use of aerial and counterpoise earth were employed by Lodge in place of his metal cones.

continuous wave transmission." Lodge also dispensed with the lower capacity area, and employed an earth connection in its place.

FESSENDEN'S WAVE CHUTE.—In 1902 **Fessenden** patented a method for recording signals on photographic paper (U.S. patent 706,743, June 26th, 1902), and in the same year he patented his Wave Chute (U.S. patent 706,746, July 1st, 1902). This was an artificial ground connected to the lower end of the transmitting conductor and connected at its outer end to the ground.

Lodge's Disc Coherer.—A detailed descriptiom of the Lodge-Muirhead system, by **H. C. Marillier,** appeared in "The Electrician" of March 1903 (246). In his paper, connections for both open and closed circuits are given, for both transmission and reception, and a description of their automatic method of transmission and reception by means of a disc coherer (Figs. 60 & 61), which consists of a steel disc revolving in a thin film of oil above a globule of mercury in a

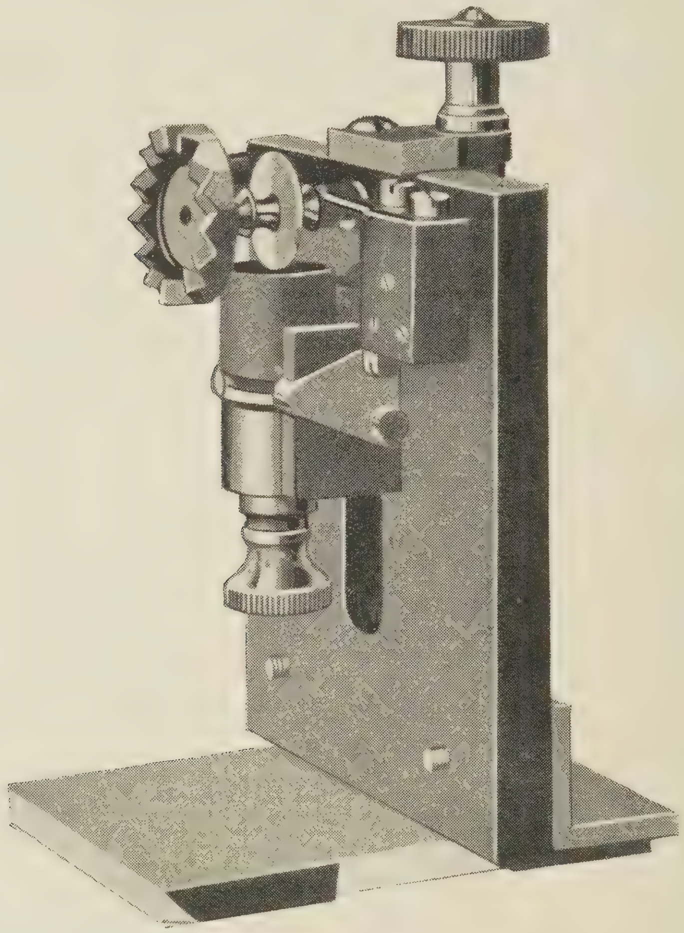


Fig. 60. The Lodge disc coherer makes use of a steel disc rotating in a thin oil film above a globule of mercury.

suitable container. (The first wheel coherer was, it is said, made by Robinson.) A patent (No. 13,521, June 14th, 1902) was taken out jointly in the names of Lodge, Muirhead, and Robinson for this coherer.

Fig. 60 is a photograph of the disc coherer taken from Dr. Erskine Murray's Handbook of Wireless Telegraphy (28). The diagram (Fig. 61) also from his book should make the action of the coherer clear with very little further explanation.

The rotation of the steel disc a (Fig. 61) keeps the detector in a sensitive condition, just separated from actual contact with the

globule of mercury b by a very thin film of mineral oil. The received oscillations momentarily break down the insulation and cause the disc and the mercury to cohere. The de-coherence is restored by the rotation of the disc. This coherer is placed directly in circuit with a siphon recorder, without the interposition of any relay, and is connected with a potentiometer to reduce the working potential to about half a volt. One volt applied across the terminals is sufficient to break down the oil film and produce coherence.

MUIRHEAD'S COHERER.—In 1907 **A. Muirhead** (851) patented a coherer which comprised a needle point in contact with or exceedingly close to a conducting surface. In use, thick oil or glycerine was caused to flow slowly past the cohering parts.

A description of **Lodge-Muirhead** portable aerials for temporary military stations capable of rapid erection appears in "The Electrician," Oct. 16th, 1903 (247).

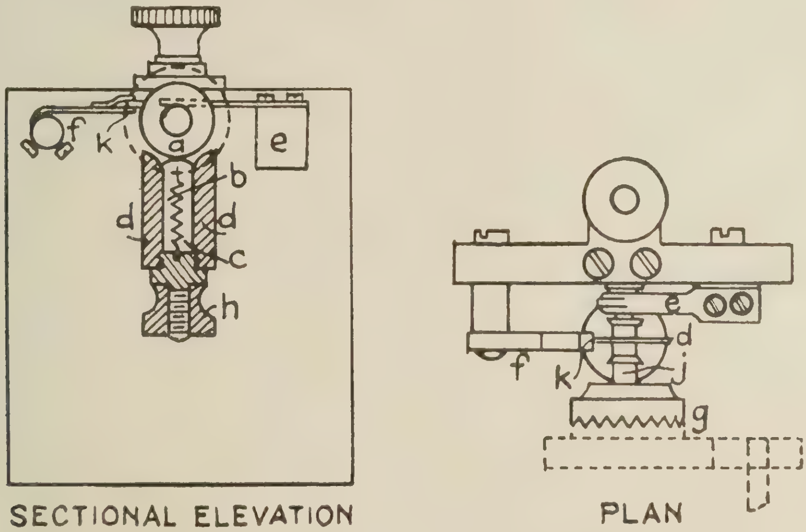


FIG. 61. Details of the construction of the Lodge disc coherer illustrated on the previous page. (*Reproduced by courtesy of Messrs Crosby Lockwood & Sons.*)

In 1905 **Lodge** employed rectifying valves (of the type used for suppressing inverse current for X-ray work) in the leads from the induction coil to the oscillating circuit (840).

Other improvements introduced into the Lodge-Muirhead system were an automatic signalling machine (841), used in conjunction with a perforator of special design. Also a special form of primary interrupter (for the induction coil), constructed of two Morse sounders. This made and interrupted the primary current about 600 times per minute, and controlled the sparking frequency. This was termed a "Buzzer." The actual contact was made and broken by means of a copper rod dipping into a container filled with mercury.

In the early days of "wireless," when the silence of the ether was almost unbroken, except for atmospherics, the author remembers hearing (at Richmond, Surrey) this system in operation between Elmer's End and Aldershot. Sometimes a group of some three Morse letters would be automatically transmitted for hours at a time. In 1906 (842) **Muirhead** patented a capacity aerial with directional properties.

During 1904 the Lodge-Muirhead system was installed under the Indian Government for communication between Burmah and the Andaman Islands, a distance of about 305 miles. In spite of the adverse conditions due to a tropical climate the installation proved most successful, the usual speed of working being from 17 to 20 words per minute.

SENATORE GUGLIELMO MARCONI.—**Senatore Marconi** may well be termed the long-distance record maker and breaker of "Wireless" Telegraphy. So great have been his achievements in this direction that his name has become a household word. **Marconi** was born at Bologna, Italy, and received his education at Leghorn and at the Bologna University, where he studied under Professor A. Righi (4a).

His first trials took place in his native town. These proving successful, he came to England and was introduced by Mr. Campbell Swinton to the late Sir William Preece, Chief Engineer of the Post Office. He was then only twenty-two years of age, and during this year (1896) took out his first patent (332) (two years previous to the advent of Marconi, Lodge had already given the first public demonstration of signalling through space, by means of Hertzian waves, at the Royal Institution in 1894).

Shortly after his introduction to Sir William Preece the Post Office witnessed a trial, first at the G.P.O., through the walls of several rooms, to a distance of 100 yards, and later, on Salisbury Plain, to a distance of two miles. From this date onwards he set up long-distance records, one after the other, with such rapidity that he astonished the whole world with his results.

In 1897 he telegraphed across the Bristol Channel, 8·7 miles, using a 20in. coil to excite the aerial.

In August 1898 successful communication was carried on by him between "The Haven Hotel," Poole, Dorset, and Alum Bay, a distance of eighteen miles.

Following this success, Marconi syntonized his transmitting and receiving apparatus, and succeeded in receiving at Poole two messages simultaneously transmitted by two transmitters at St. Catherine's, in the Isle of Wight, thirty miles distant. For aerials he employed metal cylinders elevated 25 to 30 feet above the ground, each of the two receivers having a separate aerial.

Fig. 62 shows a photograph of the short-wave transmitters actually employed during this transmission, reproduced by kind permission of the Marconi Company.

In a later experiment, at Poole, at which Professor Fleming was present, two messages were received simultaneously on

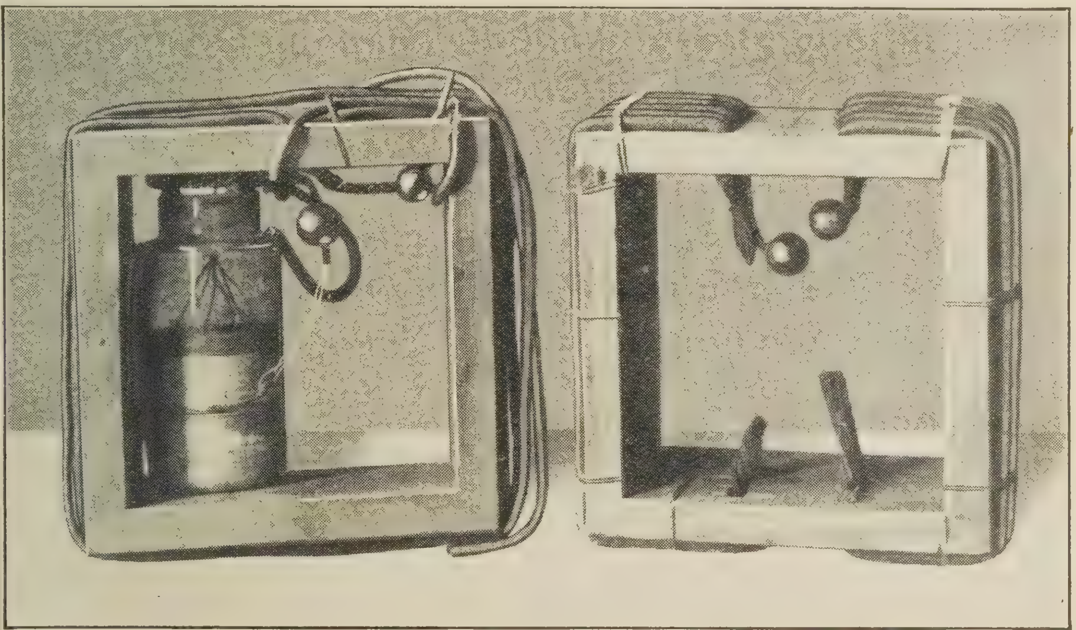


FIG. 62. Some of the apparatus used by Marconi for the short-wave transmissions in 1898 between Poole and St. Catherine's.

two different receivers, only one aerial being employed, to which both were connected.

In 1899 the Marconi Company succeeded in signalling across the Channel between England and France—from the South Foreland to Châlet d'Artois at Wimereux, near Boulogne. These tests were witnessed by Captain Ferrié, representing the French Government, the French Naval Attaché in England (Captain Fieron), Professor Fleming, and others.

MARCONI'S JIGGERS.—Marconi attributed his success mainly to the employment of receiving "jiggers," which were really transformers of peculiar construction, their particular function being to increase the electro-motive force due to the received oscillations at the terminals of the detector. These are now

in the keeping of the Institution of Electrical Engineers, and they are shown at C, D, and E, Fig. 63.

The primary coil (which was connected between aerial and earth) was wound in one layer, with fairly fine wire, and the secondary (which was connected across the coherer in series with a small condenser) with still finer wire. Marconi found that if the secondary was wound with more than one layer of wire no advantage was obtained. B and C, Fig. 63, are two of his earliest single-layer jiggers. A later form is shown at D. Here the secondary winding has only one turn, at the centre of the coil; but the number of turns is increased at each end. This he termed the "two-hump jigger." Finally, he found that the best way was to wind the secondary in four humps, as shown at E.

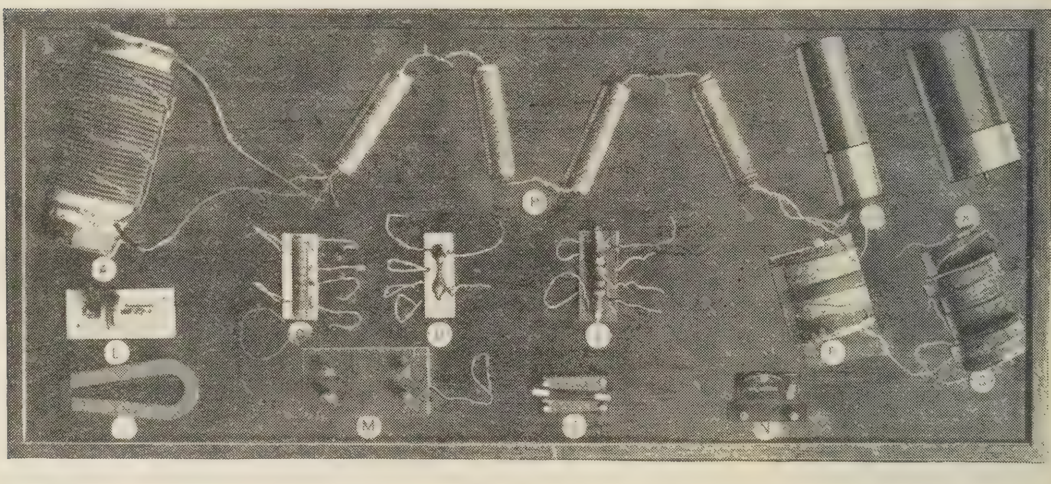


FIG. 63. A collection of Marconi's early apparatus. L and M are parts of a magnetic detector; N is the mercury iron detector referred to on page 72. (*Reproduced by the courtesy of the Institution of Electrical Engineers*).

After this Marconi succeeded in picking up signals from Wimereux at the Marconi factory at Chelmsford, a distance of 85 miles, and established communication between these two places. He also carried out extensive trials in Italy, at the request of the Italian Government, with equally conspicuous success. The Marconi Company was started in 1897, and a test was successfully made between Bath and Salisbury, 34 miles distant. The first permanent station the Company erected was at Alum Bay, Isle of Wight, and was used to transmit to a small steamer, which cruised about in the vicinity of Bournemouth.

DR. SLABY (OF CHARLOTTENBURG, GERMANY).—In this same year, 1897, **Slaby,** who had been present during some of

Marconi's trials, achieved success with very similar experiments at Potsdam (27 and 4a).

In 1899 messages were sent between a temporary station, installed at St. Thomas' Hospital, and the House of Commons.

In July 1899 very extensive trials took place during the British naval manoeuvres, the greatest distance at which ships communicated reliably being 60 nautical miles, although signals were clearly read, in one direction only, to a distance of 74 nautical miles (85 land miles).

These results were all achieved by the aid of Marconi's then newly patented jiggers.

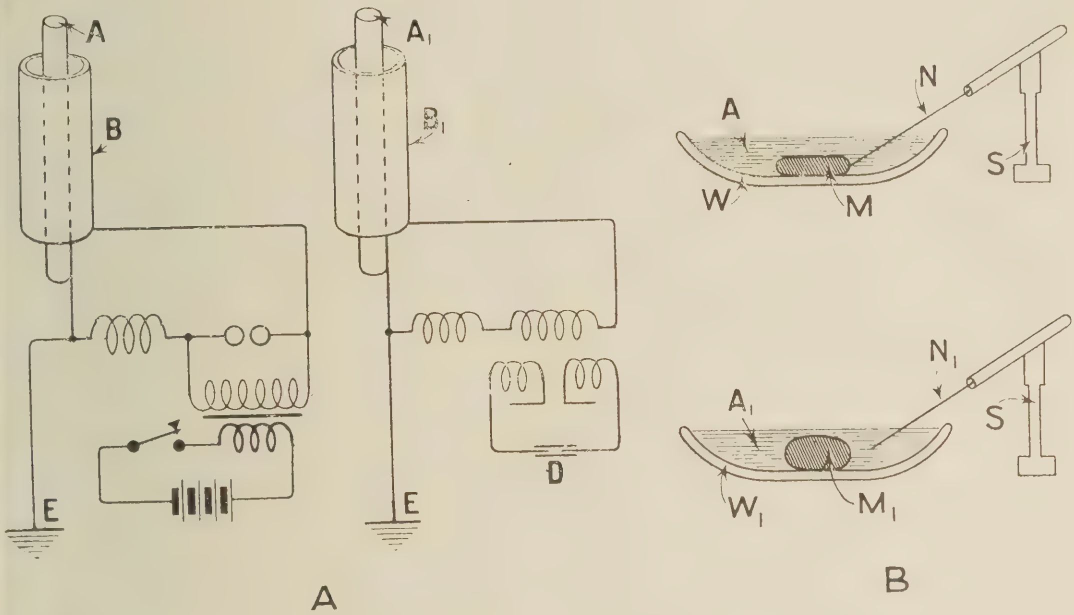


FIG. 64A illustrates Marconi's use of concentric metal cylinders both for the aerial and the tuning capacity
FIG. 64B illustrates a surface tension experiment described on page 113.

In 1899 Marconi apparatus was employed to report the progress of the yacht race between the "Columbia" and the "Shamrock," after which the American Navy Board put the apparatus to some severe tests, and two ships were employed to transmit simultaneously. This experiment had a disastrous result, rendering the received signals unintelligible.

It is interesting to note that these tests were made at the time of the outbreak of the South African War. In 1899 the War Office sent out some Marconi instruments to South Africa; but again Marconi had bad fortune. They were reported not to be working satisfactorily, owing to the presence of iron ore in the soil.

Marconi's Concentric Cylinder Aerials.—In 1901 Marconi patented an aerial (248), shown in Fig. 64A. It consisted of two concentric cylinders, which formed the capacity of an oscillating circuit. Using cylinders only seven metres high and $1\frac{1}{2}$ metres in diameter, both for transmitting and receiving (249), good signals were easily obtained between St. Catherine's, in the Isle of Wight, and Poole (31 miles). The Marconi Company equipped motor-cars for field service, using such cylinders as aerials. When travelling, the cylinders were lowered and rested along the top of the car in much the same way as the funnel of a river steamer is lowered when passing under a bridge. (**De Forest** also designed a motor-car wireless equipment carrying its own aerial (250).)

W. H. Eccles.—Between 1899 and 1900 **Dr. Eccles** was engaged in development work on the staff of the Marconi Company. One of the first things he did was to devise a method of testing coherers, to avoid the necessity of actual testing by the reception of signals on an aerial. His method consisted in plotting their characteristics. He was, I believe, the first to draw detector "characteristics," and the first "characteristics" ever published appeared in "The Electrician" of September 1901. He also carried out considerable research upon the theory of coupled circuits, and as a result the old conically-wound jiggers were superseded by plain solenoids or flat spirals.

The Thermophone.—In 1900 **Eccles** invented a detector in which the expansion of a very fine wire traversed by signals caused the alteration of a microphonic contact. This led him to the invention, in 1906, of the "Thermophone" (92), a small instrument which was actually inserted in the ear, the air waves being produced without the aid of a diaphragm by the expansion of the air in the aural passages due to the heating of the wire.

These instruments proved troublesome in use, owing to the frequent burning out of the wire by atmospherics.

This instrument is shown in Fig. 12, page 21.

In 1901 the whole world was astounded by the news that **Fleming** had transmitted the letter "S" from Poldhu, in Cornwall, to St. John's, Newfoundland, a distance of 1,800 miles across the Atlantic Ocean, where they were picked up by **Marconi**, and, shortly after, signals were also received on board the American liner "Philadelphia," fitted with Marconi apparatus, at a distance of 2,099 miles.

An interesting account of this wonderful achievement appeared in "The Electrician" of June 20th, 1902, in the report of a lecture delivered by Senatore Marconi at the Royal Institution. In this lecture, he said that for the reception of the first transatlantic signals he employed a mercury detector of the Italian Navy type. He said : " These mercury detectors were used in Newfoundland, where, on a wire elevated by kites, the first signals were received from across the Atlantic." Fig. 40, page 71, Chapter V., shows the actual mercury detector which he employed.

In 1902 the Italian Government placed the warship "Carlo Alberto" at Marconi's disposal. During the voyage he received signals from the Baltic to the Mediterranean, some of these travelling a distance of 1,500 miles, and crossing not only the sea but also passing over France and the Alps.

In 1903 signals were sent from America and published in England ; but the service broke down, and for a time signalling had to be suspended. He also sent from America a wireless message to the King of England and to the King of Italy, thanking their Majesties for the assistance they had rendered him in his work (see lecture delivered at the Royal Institution in 1905), and he pointed out that these *long-distance transmissions were hampered by daylight*. At this lecture he also showed his magnetic detector. He predicted that wireless telegraphy would eventually unite England with her colonies and America, and that some day we might realize **Lord Kelvin's** prediction of wireless messages being sent to the antipodes.

Wireless for Ships in Distress

The Origin of the SOS Call (1002).—The first suggestion for a distress signal for use of ships was made by the Italian delegates at a preliminary International Conference held at Berlin in 1903, when the use of SSSDDD was suggested. On February 1st, 1904, the Marconi Company instituted the call CQD for use on all ships fitted with their instruments, CQ being the International sign indicating a call to " all stations," and D indicating an " urgent " message. This call was also adopted by the United States, and was used until the Radio Telegraph Conference in Berlin in 1906, when the German Government suggested the use of their own distress signal SOE. At this Conference it was recommended that S should be sustituted for E, as the latter,

consisting as it does of a single dot, is so easily obliterated by an atmospheric.

The signal SOS was finally and officially adopted as a universal distress call at the Radio Telegraph Convention in 1908.

The first occasion upon which the importance of Wireless Telegraphy for life-saving at sea was brought to the notice of the public was in July 1909, when the "Republic," an ocean liner, collided with the "Florida" in a thick fog. Mr. Jack Binns, the wireless operator, was in the wireless cabin when the collision occurred, and although the walls of the cabin were splintered by the collision, and the ship was plunged into darkness, the wireless apparatus fortunately remained intact, and he bravely remained at his instruments telegraphing for help and giving the location of the sinking ship. He first got into touch with the wireless station at Siasconsett, Mass., which in turn quickly communicated with the "Baltic," the "Lorraine," and other vessels equipped with Marconi sets. The fog was dense, and the relief ships had to go at slow speed; but at length the "Baltic" arrived and all hands were rescued, both passengers and crew. Within a few months the passengers and crew of another liner, the "Slavonia," were rescued near Flores Island, the rescuing ship having picked up the "SOS" at a distance of 180 miles, and having arrived in time.

In 1912 the "Titanic," one of the largest liners in the world, collided with an iceberg, when on her way from England to America (on her maiden voyage). She was equipped with Marconi apparatus. Her distress signals were picked up by several vessels, who made all haste to the rescue, but unfortunately she had already gone down when they arrived, and they were only able to rescue between 800 and 900 survivors, who had taken to the boats, out of some 2,900 who had boarded her at Southampton. The former certainly owed their lives to the wireless installation, it being unlikely that any would otherwise have survived.

In 1913, in a storm, the "Volturno" caught fire in mid-Atlantic and called for help. The "Carmania" heard the call, and, in turn, told the news to other ships, with the result that ten ships arrived to the rescue, and all those who had remained on board (some 500) were saved. (A thrilling account of these rescues is given in "Discovery," by R. A. Gregory (39).)

CHAPTER IX.

Further Investigations

Orling and Armstrong's Investigations.—In 1902 a very novel system of "Wireless" communication was introduced jointly by **Orling**, a Swedish electrician, and **Armstrong**, a London engineer, who entitled their invention the "Armorl" system (4b) and (28); also (88), (91), (843), (844), (162). Their receiver is based on the action of the "Lippmann" capillary voltmeter, invented by **Lippmann** in 1874.*

A glass tube, drawn out to an extremely fine bore at its lower end, dips into a large vessel filled with sulphuric acid. The tube is filled with mercury, and by forcing this mercury down (say by blowing into the top of the tube), and allowing it to retract by capillary action, any little bubbles of air in the narrowed end of the tube are removed and the acid comes into contact with the mercury, which by capillary action rises with it a short distance up the tube.

Under the action of extremely small voltages applied across the two liquids changes of surface tension occur, with corresponding changes in the height of the mercury in the finely drawn out part of the tube, which are easily observable with a small microscope or magnifying glass and may be recorded photographically.

Surface Tension Experiment.†—A very pretty experiment was shown at the Wonders of Science Exhibition, held at Surbiton in 1911, by J. Wearham, illustrating the effect of electrical potential upon surface tension. Fig. 64B illustrates the experiment.

W is a watch glass containing a large globule of mercury M, well covered with a dilute solution of sulphuric acid A (about 1 in 7). N is a steel needle held in a suitable support, which is dipped down through the acid until it just touches the mercury. Owing to the action of the acid upon the mercury and the needle a potential difference exists between them when they

* In 1913 **Stoecklin** improved the design of the capillary voltmeter and by means of his instrument carried out investigations as to the polarity of received impulses after rectification by a crystal (719).

† **R. Whiddington** has shown that small globules of mercury injected into a tube containing dilute sulphuric acid, inclined at a slight angle to the horizontal, are caused to travel up the tube against gravity when a current is passed through the acid. This phenomenon was carefully investigated by **J. E. P. Wagstaff** in1924 (1026).

touch, and the mercury globule, owing to surface tension effects, alters in shape, as shown at M_1, and shrinks away from the needle point with a slow motion, gradually returning to its old shape and touching it again. This process is repeated for an indefinite time.

THE ARMORL CAPILLARY DETECTORS.—In one form of Armorl detector (see Fig. 65a) the capillary tube is supplied with mercury, from a tank M, at a steady pressure, so that a globule is always ready to drip off its end on to a delicate

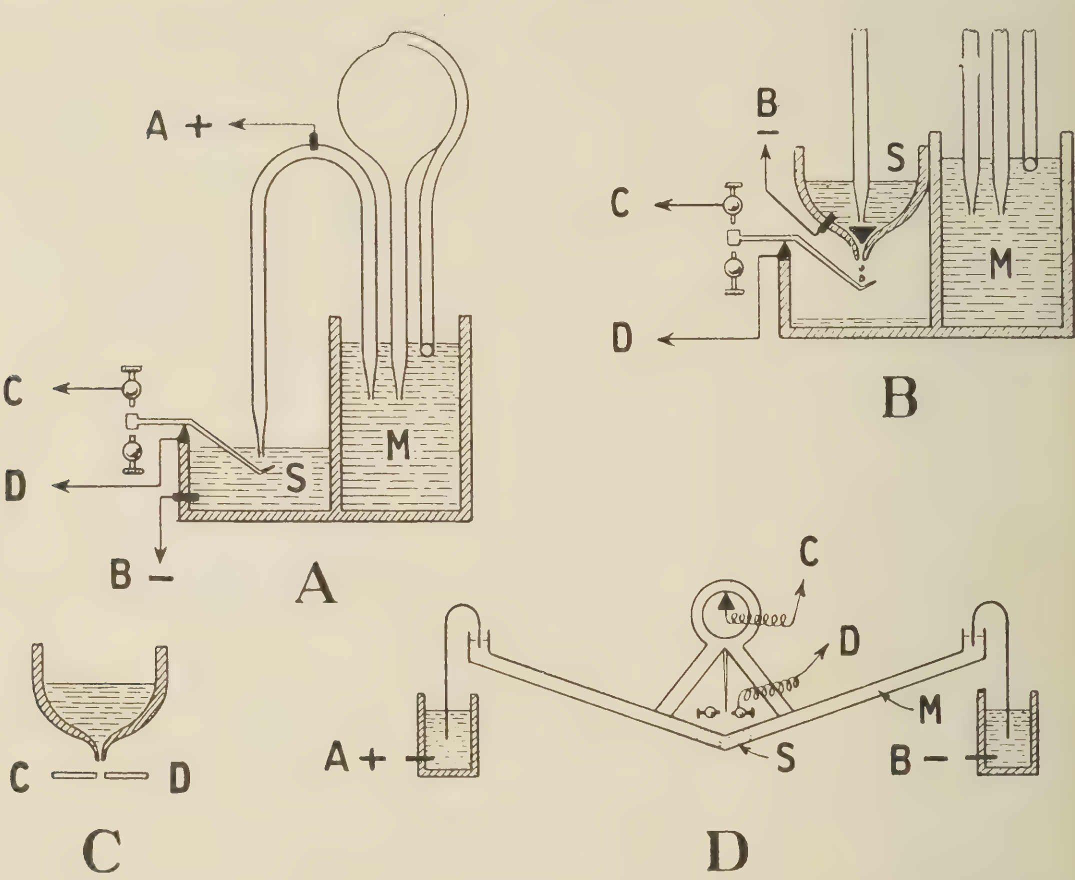


FIG. 65. Various forms of the Armorl capillary detector, which depends for its action on the changes in surface tension at the surfaces of mercury and dilute sulphuric acid when a minute potential difference is applied between them.

lever arm of platinum placed just beneath it, and, like the fine end of the tube, submerged below the surface of the acid in a small tank S.

The minutest potential difference applied between the mercury M and the acid S will cause a drip of mercury to become detached and fall on to the lever arm, which, being delicately adjusted (like a seesaw), overbalances and allows the globule to roll off into the bottom of the tank ; the upper end of the lever arm during this moment comes into contact

with a stud, and acts as a relay to a local circuit C D containing a Morse inker (the acid is the negative pole and the mercury the positive pole of this receiver).

Fig. 65b shows a modification of the arrangement shown at A. In this case the capillary tube containing mercury leads into a small chamber S, beneath which is a minute hole. Mercury is poured into this chamber until its pressure is sufficient to force a drop of it through the hole, then some acid is added which floats above the mercury. Every time an electrical impulse causes a drop of mercury to pass from the end of the capillary tube into the chamber S an equivalent drop falls through the bottom on to the lever below.

In another form, Fig. 65c, the drop of mercury M, immediately after it leaves the capillary tube, during its descent bridges a tiny gap between two adjacent electrodes C and D, and so closes the local circuit.

In yet another form, Fig. 65d, a long glass tube, sagging slightly at its centre, is delicately poised on a knife edge, like a seesaw. A few drops of acid S lie in the centre of the tube, while the rest of the tube on either side of the acid is filled with mercury M. At each end of the tube, wires dip into the mercury and hang vertically downwards into two small cups A and B, also filled with mercury.

A slight potential difference applied between A and B causes the little drop of acid in the tube to move slightly to one side, destroying the balance of the tube, and this movement brings two studs of a local circuit C D into contact and operates a recording instrument.

For transmitting, a constant current is employed, supplied by a battery connected through a Morse key to two rods of metal driven into the ground, to a depth of about 18ins., and about 12ft. apart. Two similar rods, separated by a similar distance, driven into the ground at the receiving station, pick up the earth currents from the transmitter and convey them by wires to the capillary detector. It has been stated (4b) that this system "has not worked to a distance of more than 20 miles." Even if this distance has been achieved, so many objections to this method exist (interference due to leakage from electric mains, etc.) that it has not proved practicable for ordinary use.

Orling's Jet Relays.—Fig. 66 shows another invention, due to **Axel Orling,** called a Jet Relay. This has been success-

fully used at a station at Seaford, England, where, by its aid, Hertzian wave signals were recorded from Coltano, near Pisa, Italy (4d). Its action is as follows: A stream of acidulated water is fed through a tube T, and, as it leaves the nozzle, flows lengthways down a length of very fine quartz fibre F, and then continues in a fine stream, finally impinging near the top edge of a conducting plate M.

A second fine quartz fibre H, fitted like a bow string to a more rigid rod of glass, rests lightly against the vertical fibre F, and is attached at one end to the moving coil of a syphon recorder or moving coil galvanometer.

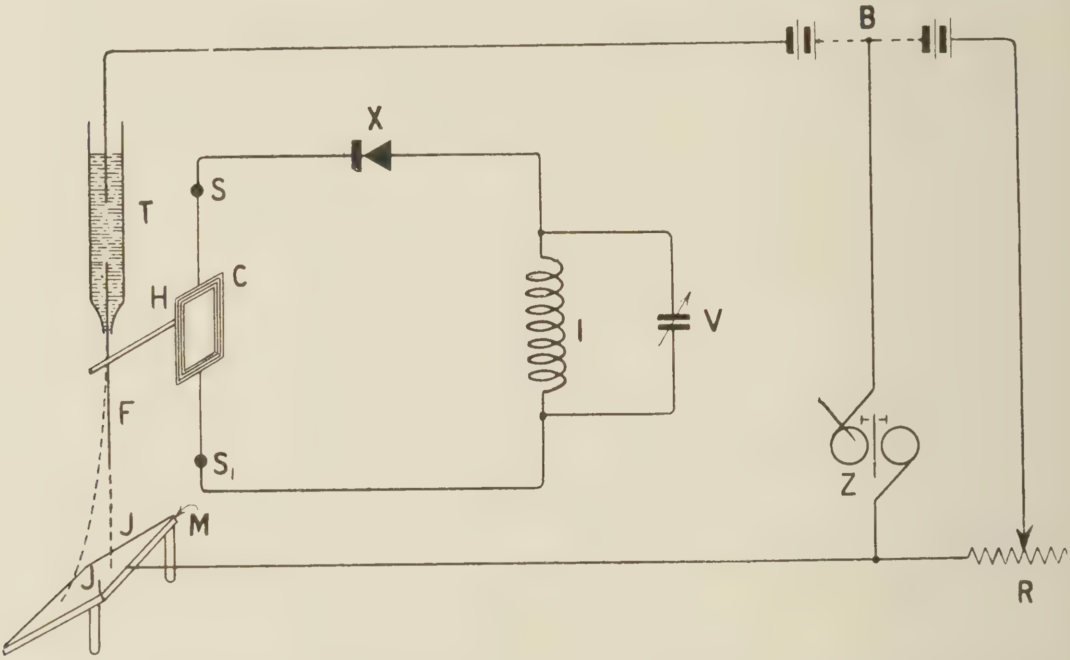


FIG. 66. Illustrates the application of the Orling Jet Relay to the recording of Morse signals. The inductance I is coupled to the usual aerial circuit.

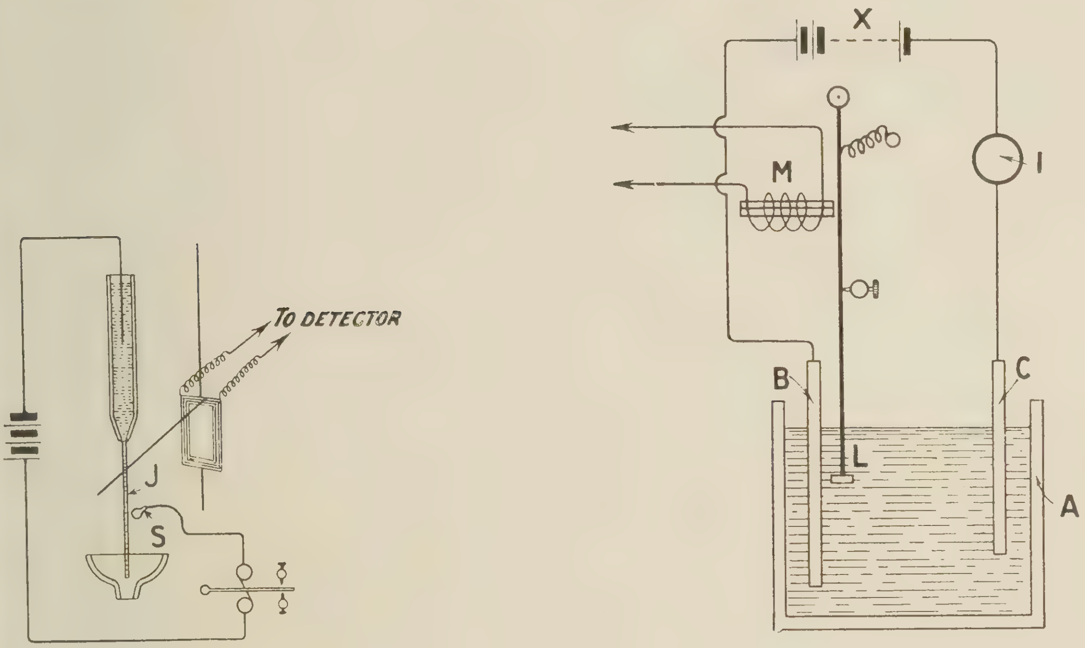
If the coil moves ever so little, the quartz bow string H presses on F and displaces the jet of liquid to a position indicated at J_1, and, the column of liquid becoming longer, exhibits an increased resistance and operates a polarized relay Z. This instrument, when properly adjusted, is so sensitive that it will respond to currents as small as 10^{-8} ampère passing through the moving coil C. It will record quite faint Morse signals, as picked up from any stations radiating Hertzian waves. For this purpose a crystal detector X and inductance I, tuned by a variable condenser V, are coupled to the usual aerial circuit.

There is a later pattern of Orling jet relay, in which the jet of acidulated water is directed on to a knife edge of

glass and wets the two sides of it. These two wet sides of the glass form the two arms of a Wheatstone Bridge, in the bridge circuit of which is connected the recording instrument.

This arrangement is even more sensitive, and movements of the jet too minute to be observable by the eye can be recorded.

Yet another form of Axel Orling Relay* is shown in Fig. 67a. In this the liquid jet J, on being deflected, makes contact with a stud S and operates as relay. It has been found in practice that it acts perfectly with a current of only 0·6 microampère, and there is no trouble due to sticking of contacts (92).



A B

Fig. 67 A (left). A modification of the Orling relay shown in in the previous figure.
Fig. 67 B. An electrolytic relay, due to Walter, which depends for its action on the depolarising of a cell in series with the recording instrument and battery.

L. H. Walter's Electrolytic Relay (861).—A in Fig. 67b is a cell containing a solution of ammonium borate, B is an anode of aluminium or magnesium, C is a carbon cathode. (The anode is polarized by the current from battery X in the secondary circuit, which passes through and operates an instrument I on its way through the cell.) M is an electro magnet in the circuit carrying the weak current impulses, with which it is desired to control the powerful currents passing through I.

* For other jet relays see, Hall's Air Jet acoustic relay, U.S. patent 1,160,072 and British patent 144,250; also Lyon's Harmonic Jet (977)

Each impulse in the primary circuit through the magnet M causes the light lever arm L to be attracted and momentarily to touch the anode (in point of fact, actual contact between the contact piece and the anode is unnecessary if the applied voltage is near to the critical value of the electrolyte).

The operation of the relay depends upon the fact that the immersed anode of such a cell can be instantly depolarized by touching it with a platinum wire or a carbon rod held in an insulated holder or connected to the cathode wire. It is claimed that this relay will deal with a current of several ampères at least.

The Johnson-Guyott System.—This system (38), (847), (848) was invented in 1903 and tested from a Martello tower, near Pevensey, at about that date ; but was impractical, so far as long-distance telegraphy was concerned. It was similar to that of Dolbear. The two ends of the secondary of the induction coil used for transmitting were connected to earth and to a capacity respectively, without the employment of any spark-gap. **A. T. M. Johnson** (who was a teacher of music) suggested tuning by resonance, at audible frequencies. He fitted his coil with a contact breaker that could be tuned to vibrate at any desired audible frequency,* and having tuned the reed of his contact breaker to some selected note, signals were transmitted with a Morse key in the usual manner.

To receive the signals he employed a telephone of special design, fitted with one or more reeds tuned to the same musical note, or a form of loud speaker containing a tuning fork which was exactly in tune with the reeds and was placed above them in a sort of sound box to which a horn was attached.

A, B, C, and D (Fig. 68) give a general idea of this system. A shows a set of reeds (M M^1, M M^2, etc.) used to produce different notes. These project from a disc D, which can be revolved by a knob K so as to bring the desired reed in front of the iron core of the induction coil. By the side of each contact reed (M^1, M^2, etc.) is a master reed M. This is more clearly shown in Fig. 68b. A contact reed M^1 is fitted with a soft iron pole piece I. When the primary current is going through the induction coil this reed vibrates in front of a contact screw S, which is adjusted until M^1 (which acts as a

* Both **Helmholtz** and **Bell** had employed tuned reeds, the former as a contact-breaker and the latter in connection with his early attempts at making a telephone.

contact breaker) acquires the same frequency as that natural to the master reed M. When the latter begins to vibrate, the operator knows that the coil is transmitting the required note.

C represents a telephone receiver, fitted with two reeds, each set to respond to a different note, and therefore capable of receiving from two differently tuned contact breakers. D represents Johnson's Loud Speaker, with tuning-fork resonator in place of reeds.

ATMOSPHERIC DISTURBANCES AND OBSERVATIONS OF LONG-DISTANCE TRANSMISSIONS.—Even before the discoveries of Hertz, **Sir Oliver Lodge**, while engaged in researches in connection with the discharge of Leyden Jars, surmised that lightning discharges were probably of an oscillatory character.

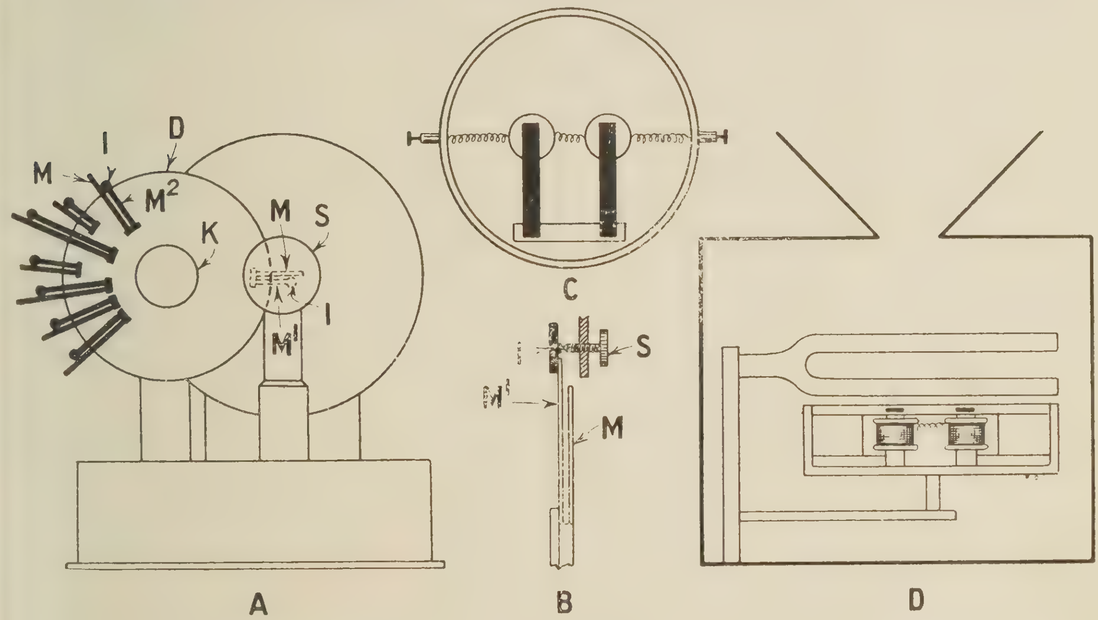


FIG. 68. The use of a tuned reed on the contact breaker of a transmitter, and a telephone or loud-speaker using a similarly tuned reed or reeds, was suggested by A. T. M. Johnson.

In 1895 **Popoff** connected a coherer to a vertical exploring rod or aerial, and showed that distant thunderstorms created natural electric waves, which could be detected by the coherer, thus proving Lodge's surmise to have been correct, and between 1895 and 1896 Rutherford, Minchin, and others applied the Hertzian method to the study of atmospheric electricity.

In 1901 **Feriyi** recorded thunderstorms 100 miles distant.

In 1903 **Turpain** showed that observations of atmospherics were of utility in weather forecasting (41), (42).

Dr. W. H. Eccles introduced a simple method of making records when listening-in at a telephone receiver. Vertical marks are made by hand, the distance between them roughly representing the time between the disturbances, and the length of the vertical lines the loudness of the observed sounds (see 42, and Dr. W. H. Eccles' paper before the British Association at Dundee (43)).

In 1912, in a paper "On the Diurnal variation of the electric waves occurring in Nature, and the propagation of waves round the Bend of the Earth," Eccles showed that in ionized air the velocity of electric waves may be increased, and that owing to the increased velocity of electric waves, as they travel through the ionized layer (or Heaviside layer) of the atmosphere, they were bent down or refracted so that they were enabled to reach round the earth.

In certain cases the ionic refraction would be so great that the wave might be brought right down again to the earth's surface and its effective range reduced.

Both Dr. Eccles and **Dr. J. A. Fleming** (45) have pointed out that the decreasing density of the atmosphere should produce a certain amount of refraction, independent of the ionic refraction.

In his book, "The Principles of Electric Wave Telegraphy and Telephony," Fleming states that ordinary ship transmission and reception has "two or three times greater range by night than by day, when using a 600-metre wavelength."

For longer waves the difference may be all the other way. Senator Marconi called attention to this in his lecture of June 2nd, 1911, at the Royal Institution, when he stated that for waves 4,000 to 5,000 metres long, the transatlantic signals are sometimes stronger by day than by night. Speaking of diurnal variations, Marconi also said: "Waves about 4,000 metres in length, crossing the Atlantic from West to East, yield strong and steady signals all day at Clifden, which gradually weaken after sunset, reaching a minimum about an hour and a half afterwards. The signals at Clifden then gradually increase in intensity till after sunset at Cape Breton, when they attain a maximum which is occasionally very high. During the night they are variable in strength. Slightly before sunrise at Clifden the signals grow stronger, and sometimes pass quickly to a high maximum; they then

dwindle to a marked minimum about two hours after sunrise at Clifden, and then return to the normal day strength."

Similar observations have also been made by Eccles (87) and **Airey**, who conducted experiments simultaneously between Newcastle and London and published their results in 1911.

Appleton and **Watt** gave a very valuable paper on "Atmospherics" before the Royal Society in 1923 (48); they showed that only about half the atmospheric disturbances heard as X's in a wireless receiving station are oscillatory in character, and that nearly as many of the disturbances are aperiodic. In ten days they observed 590 atmospherics. The whole of their observations were made by means of a cathode-ray oscillograph (Fig. 69). This consists of a heated filament in a partially exhausted bulb. In front of the filament are two pairs of plates, arranged to be at right angles to one another, and the cathode stream from the filament passes between these plates and impinges on a fluorescent screen, or coating of fluorescent material, on the inside of the glass of the bulb (opposite to the filament). As the cathode beam impinges on the screen a bright spot of fluorescent light is seen, and when one pair of plates is connected to a source of alternating current it causes the cathode beam to oscillate to and fro, across the fluorescent screen, so quickly that the spot of light appears like a straight line running horizontally across the screen. The aerial of the receiving station is connected through a suitable amplifier to the other two plates of the oscillograph. Whenever a disturbance reaches the aerial the straight line of fluorescence on the screen is deflected up and down, so that it takes on a wave form and shows the true characteristics of the disturbance. At present, it has not been found possible to take photographic records; but they can be clearly observed by eye.

On June 27th, 1923, Watt gave a demonstration, and showed the oscillograph in action, at a lecture he delivered at the Institution of Electrical Engineers before the Radio Society of Great Britain. (See also Oscillograph of Wood & Dufour, Ref. 1107, 1108).

Professor E. W. Marchant also spoke about the work of Appleton and Watt, in a lecture before the Radio Society on May 23rd, 1923 (49). In this paper he refers to the observation of **Stoyle**, in Strasburg, who noted that when a particular condition of the sky occurs—which he describes as "curls"—

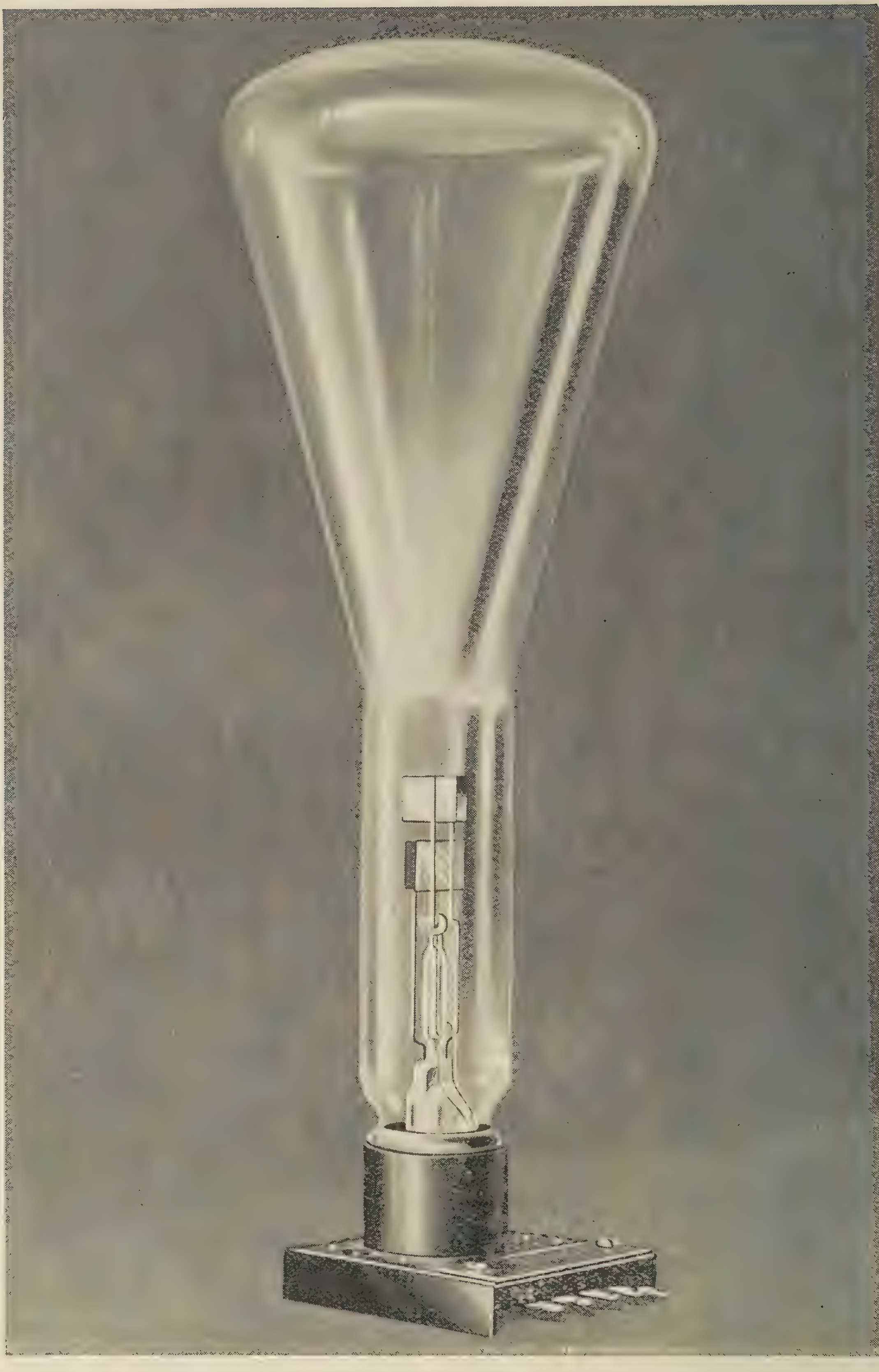


FIG. 69. The type C Cathode Ray Oscillograph produced by the Standard Telephones and Cables, Ltd.

preceding a barometric depression, atmospherics are particularly troublesome.

For further references to Atmospheric Investigations see foot-note.*

NIKOLA TESLA.—Tesla, in 1904, showed that lightning discharges produce stationary waves along the earth's surface. (His work in this direction is described later in this chapter.)

Nikola Tesla was born in Smiljan, Lika, border country of Austria-Hungary, in 1857 (47). He was the son of a clergyman and of Georgiana Maudic, a woman herself not unknown as an inventor. He was educated first in the elementary school of his native place. He then went to a public school at Gospic, Lika, for four years ; and thence for three years to a school at Carlstadt, where he graduated in 1873. His parents originally wished him to enter the Church ; but he prevailed upon them to send him to the Polytechnic at Gratz, where he studied mathematics for four years, followed by two years' philosophical studies at the University of Prague, Bohemia.

He made his first electrical invention in 1881, at Budapest, Hungary, a telephone repeater, and conceived the idea of his rotating magnetic field. He then travelled in France and Germany, and finally settled down in the United States in 1884 and became a naturalized American citizen.

Among the inventions which lie to his credit are systems of Alternating Current Power Transmission, known as two-phase, three-phase, multi-phase, and polyphase generators of High-Frequency Currents, etc.

In 1891 he showed that it was possible to transmit energy through a single wire " without return."

In 1891 he also invented the " Tesla Transformer," and carried out a series of researches with regard to the effects and phenomena connected with High-Frequency Oscillations.

In 1893 Tesla suggested the possibility of Wireless Telegraphy and the distribution of electrical energy by means of stationary waves on the surface of the earth, using the entire world as a conductor. Six years later, during a thunderstorm in the vicinity of his station in Colorado, he noticed that as the storm passed away into the distance his instruments gave

* W. Austin (57) (67-69) (1023), M. Abraham (72), A. M. Curtis (78), G. L. Farrand, H. H. Beverage, H. E. Campbell (57), J. P. Henderson (1022), C. A. Hoxie, F. K. Vreeland (57), Prof. Marchant (46), G. W. Pickard (57) (71), Round and Tremellen (44), E. Roth (77), K. Stoye (74), L. B. Turner (73), G. N. Watson (57), C. T. R. Wilson (57), S. Weidenhoff (76), E. Lübcke (1063), and many other workers.

fainter indications of it, until they ceased altogether ; but, as he anticipated, they gradually began to grow again in intensity, until, after passing through a maximum, they grew fainter and again ceased. This phenomenon repeated itself over and over again many times in regularly recurring periods, and Tesla realized that he was observing stationary waves. As he says in "The Electrical World and Engineer," of New York, March 5th, 1904 (28) : "As the source of the disturbances moved away the receiving circuit came successively upon their nodes and loops. Impossible as it seemed, this planet, despite its vast extent, behaved like a conductor of limited dimensions." In 1905 Tesla took out patents. In British Patent No. 8,200 he claims to have devised apparatus capable of generating electrical disturbances, "not only approximating to but even surpassing those of lightning," and he further claims to have reproduced, by its aid, the phenomena of "Stationary Waves" on the Earth, or World Waves. By means of such stationary waves, he professed to transmit electrical power without the employment of cables.

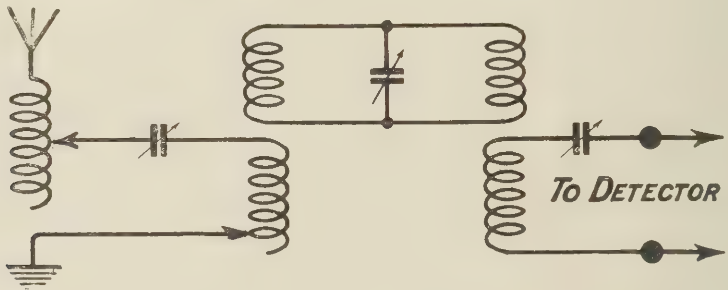


Fig. 69A. Diagram showing the connections of the Marconi Multiple Tuner.

The Introduction of the Marconi Multiple Tuner. In 1907 a very important patent was taken out in the names of the Marconi Co. and C.S. Franklin.* (British Patent No. 12960/07.

This patent formed the basis of the Marconi Multiple Tuner, an instrument marking a great step forward in the development of practical wireless. A great increase of selectivity was obtained by the introduction of an intermediate tuned circuit between the aerial inductance and a tuned circuit operating the detector.

* See also British Patents Nos. 11575/97 and 15909/06.

CHAPTER X.

The Employment of Ether Waves of Shorter Wave-length than those discovered by Hertz, for Radio Telegraphy and Telephony (722–730).

The Heliograph

HELIOGRAPHY, or the science of signalling with the sun's light by means of mirrors, would seem to have been well known at least as early as the eleventh century; for, according to an article published in "The Athenæum," 28th January, 1882 (see "Chambers's Encyclopædia," 1895 edition), there was at that early date an extensive system of signalling by means of mirrors, placed on the summits of high towers, whereby most of the cities in Algeria could communicate one with the other when the sun shone and the atmosphere was clear; but what kind of code was adopted does not appear to be known.

Mance's Heliograph.—Flashes of sunlight can so easily be adapted to the Morse code that it is not surprising to learn that about the year 1877 **Mance** devised a heliograph which was largely used in military campaigning. **Atkinson, Drummond,** and **Begbie** also were responsible for various forms of the instrument which are fairly well known.

Given a clear atmosphere, and the absence of physical obstacles, such as woods or ridges, it is surprising to what great distances messages can be sent by heliograph. French engineers in Algeria have found the instrument serviceable at a distance of 170 miles, and in California distances of even so much as 190 miles have been successfully covered.

During the Boer War General Buller got into communication with Ladysmith, then besieged by the Boers, by means of a heliograph.

The Photophone.—Between 1872 and 1873 **May** (an assistant of Willoughby Smith) (50) discovered that selenium* conducted electricity very much better when brightly illuminated than when it was screened from the light.

In 1878 **Graham Bell** and **Sumner Tainter** made use of this property of selenium in a photophonic receiver, for which

*This mineral was discovered in 1817 by Berzelius, a Swedish scientist, who found it as a by-product in the manufacture of sulphuric acid from iron pyrites.

It has been shewn (99) that the resistance of selenium changes with moisture, and it has been employed in the construction of a special form of hygrometer.

they took out several U.S. patents (301), (302), (303), and showed 50 different ways in which a beam of light could be controlled by the voice (54) and used to convey speech to a distance.

In Fig. 70b the speech is shown as being reproduced by focussing the voice-controlled beam of light B, by means of a parabolic mirror on to a selenium cell connected in series with a battery A and a telephone receiver P. In their earliest experiments they employed a steady beam of light, such as a beam of sunlight reflected from the surface of a

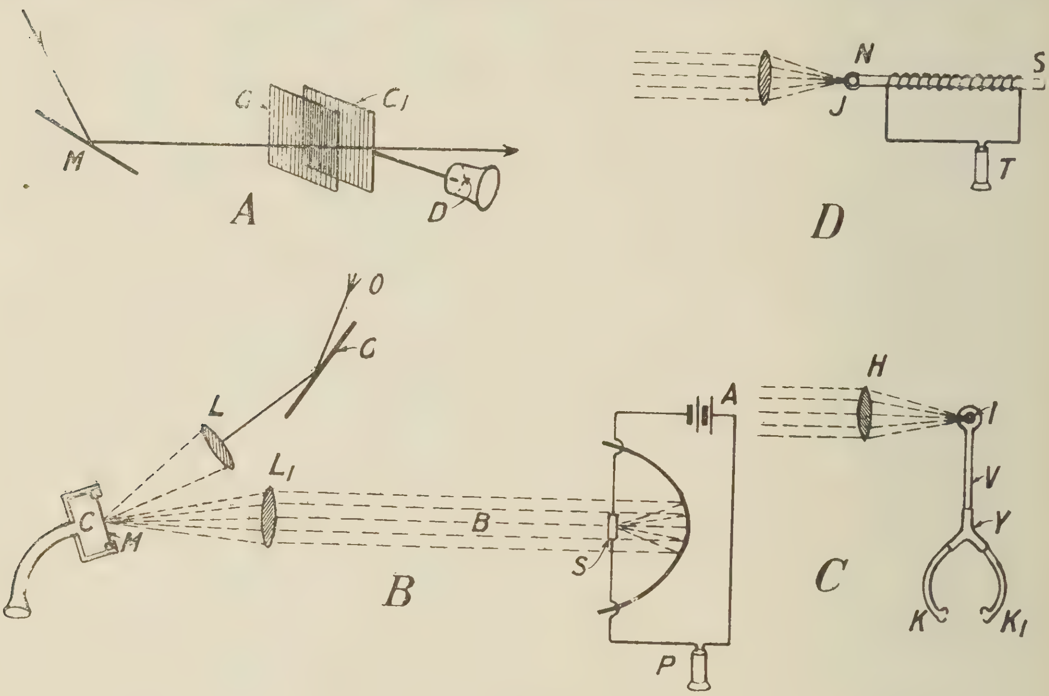


FIG. 70. A, B, and C illustrate some of Bell and Tainter's methods of photophonic transmission and reception. D shows a Magnetic Photophonic Receiver.

mirror M. Fig. 70a. This they passed through thin metal gratings (of fine parallel vertical slits) one of which, G, was fixed, while the other, G_1, was attached to a diaphragm D; when the latter vibrated in response to sound waves impinging on it, its grid G_1, acquired a lateral horizontal motion, so that it obstructed the passage of the beam of light through G in greater or less degree. The articulation by this arrangement was by no means perfect, and an amusing incident is quoted by W. Ackroyd (54). During one of their experiments, Tainter was speaking on a beam of light with one of these instruments and Bell was listening in the distance. Tainter said the most unlikely thing he could think of: "Put me to bed." At the receiver Bell thought he heard him say: "Good

piece of bread." After considerable experiment, they were able to obtain quite clear articulation. One of their most satisfactory methods of light modulation is shown in Fig. 70b.

They employed a steady source of light O (such as sunlight); this they reflected (from the surface of a mirror G, placed at a suitable angle) through a lens L, which brought it to a focus on a thin diaphragm of silvered glass M, which could be made to vibrate in response to the human voice, (conveyed by a speaking tube into a small chamber C immediately behind it). The ray of light, after striking the diaphragm M, was reflected from its surface through other lenses L^1, which con-

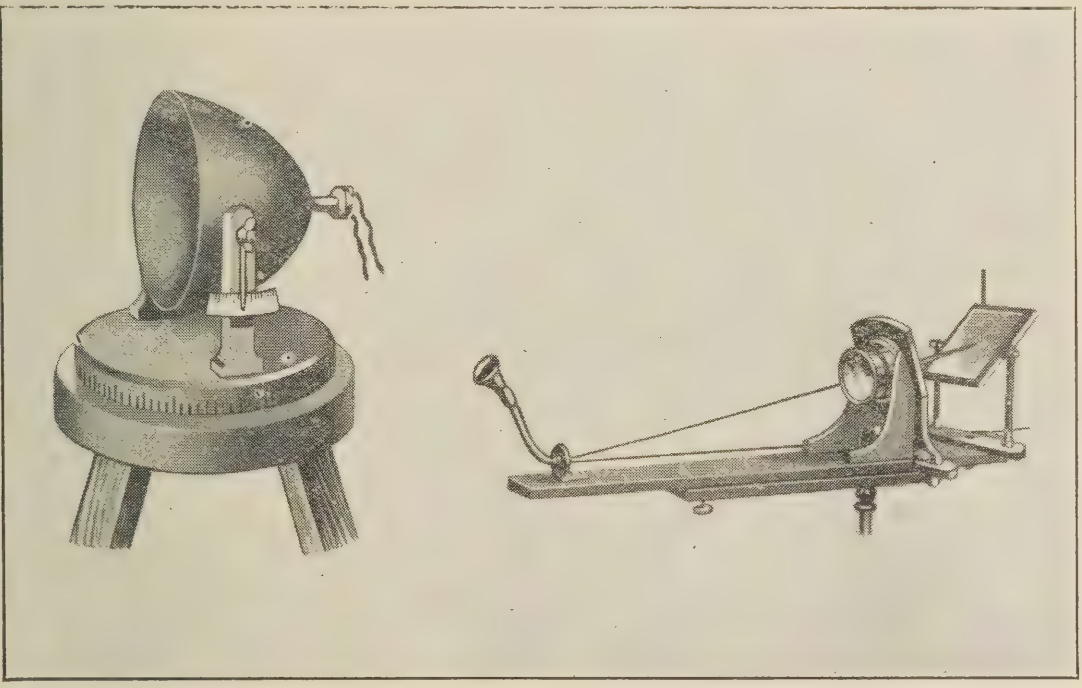


FIG. 71. The type of transmitter (right) and the receiver (left) employed in Bell's Photophone.

(*By courtesy "Engineering*.")

verted it into a parallel beam B. Every sound spoken behind the silvered diaphragm caused it to vibrate, and produced corresponding variations in the intensity of the beam of light.

Fig. 71 is a photographic reproduction of Bell's Photophone (Engineering, Nov. 5th, 1880).

During one of these experiments, in 1880 (54), Bell was in his laboratory, with his selenium cell receiver near to the window, in L—— Street, Washington, while Tainter was speaking on a beam of light from the tower of Franklin College, some 250 yards distant. As Bell put the telephone to his ear, he clearly heard the words: "Mr. Bell! If you

can understand what I am saying, come to the window and wave your hat!"

At the Chicago Exhibition, in 1893, using the steady light from an arc in place of sunlight, and controlling it in the manner previously described, Bell showed an exceedingly simple receiver, in place of a selenium cell, battery, and telephone (see Fig. 70c).

The beam conveying the voice variations is brought to a focus, either by a parabolic mirror or a lens H, on to a small fragment of charred cork I placed in a bulb at the end of a glass tube V; a tube Y connects the bulb to two vent tubes K and K_1, which are placed in the ears of the listener. The variations of heat intensity from the beam, in this case cause corresponding variations in the volume of the cork, the expansion and contraction of which, within the small glass bulb, produce corresponding movements in the column of air in the tube. These movements are heard as sound. (The author repeated this experiment in 1908, using a speaking arc as transmitter, and found that at a distance of 50 yards the speech reproduction was exceedingly clear and perfect (56).)

Mercadier's Photophone Reproducer.—Mercadier (51) used a plate of mica, covered with lampblack in a tube, instead of charred cork (50). Many other substances will act in the same way as sound producers if placed in a glass bulb in place of the charred cork. Chips of wood and other solids, liquids, and even gases, make quite efficient sound reproducers when placed in a sonoriferous beam. Even the smoke from a cigar will reproduce sounds. In earlier experiments Bell and Tainter showed that diaphragms of various substances, placed at the opening of a tube leading to the ear, would reproduce sounds when placed in a photophonic beam. Thin sheet ebonite was particularly good for this purpose. Thermopiles have also been successfully employed connected to a telephone receiver.

Magnetic Photophone Receiver.—**Erskine Murray,** in his book "Wireless Telephony," describes another form of receiver. The beam of voice-controlled light in this case is focussed on to a thin-walled bulb of iron J (Fig. 70d), which forms one pole of a permanent magnet NS. Round this magnet is a winding of insulated wire connected to a telephone T. The heat variations, due to the voice in this case, cause corresponding variations in the strength of the magnet,

which in turn induces currents in the coil of wire, which pass through the telephone and are interpreted as sound.

Following Bell's original photophonic experiments in 1881, **Andrew Jamieson**, of Glasgow (50) and (51), made use of König's manometric flame (54), (108) as a photophonic transmitter, thus controlling the light at its source. The plan adopted by Jamieson, and improved by **Giltay** (who employed acetylene as an illuminant), was as follows : The gas on its way to the jet passed through a small chamber and filled the

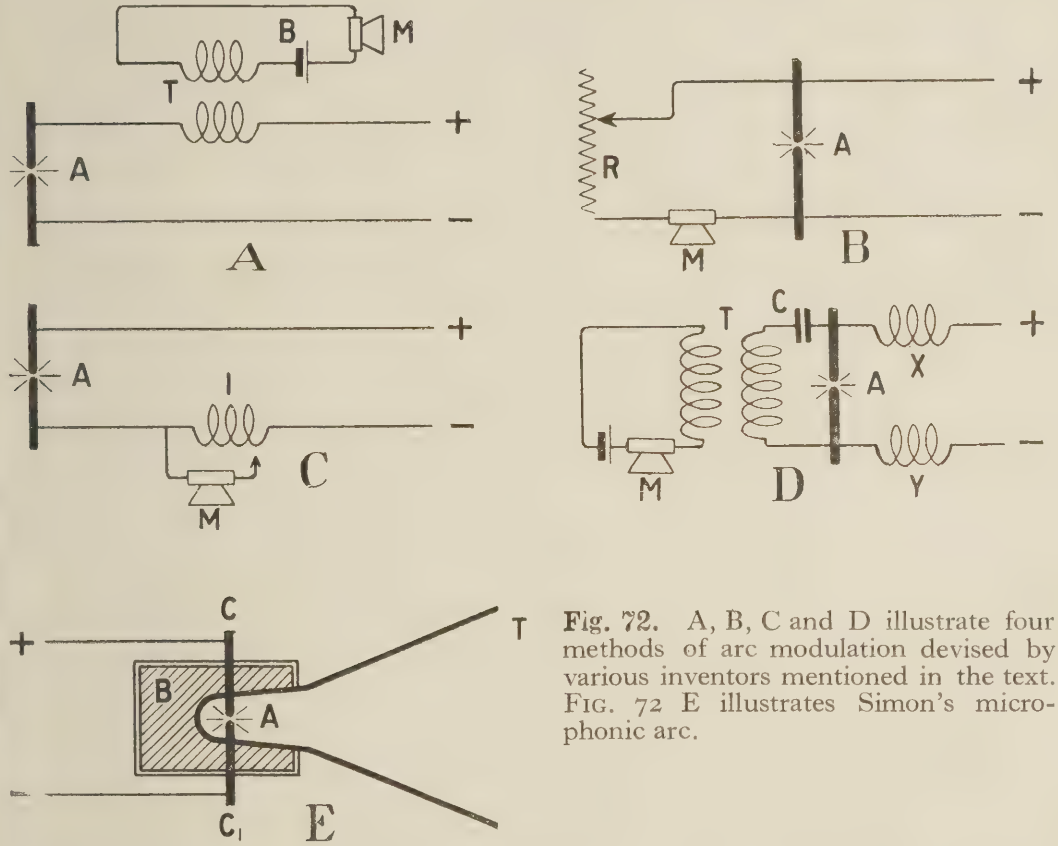


Fig. 72. A, B, C and D illustrate four methods of arc modulation devised by various inventors mentioned in the text. FIG. 72 E illustrates Simon's microphonic arc.

space on one side of a thin diaphragm. The space on the other side of the diaphragm led to a speaking tube ; consequently, when anyone spoke into the tube, the diaphragm vibrated and caused corresponding variations of gas pressure. These caused the flame to flicker and produced corresponding variations in the strength of the light.

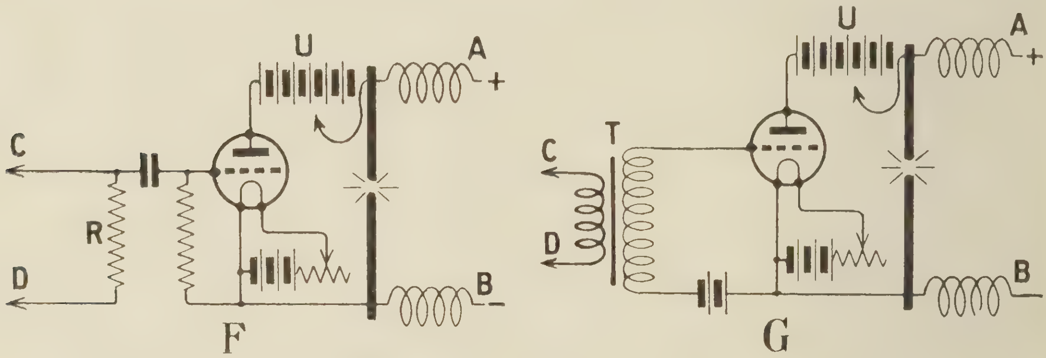
In 1897 **Bell** and **Hayes**, in America, showed that if a circuit containing a battery and a microphone were coupled inductively to a D.C. arc, the arc would audibly reproduce the voice, and that at the same time the light intensity varied. They applied this discovery to photophony.

Independently, and only a few months after the discovery

L

of the speaking arc and the filing of an American patent (No. 654,630) on June 7th, 1897, by Hammond V. Hayes, **H. T. Simon,** in November 1897, made similar discoveries, which he communicated to the Erlanger Physico-Medical Society at that date.

There are several ways in which an arc can be controlled by the voice (50) and (56). **Simon** and **Reich** connected one of the main supply leads through the primary of a transformer T (Fig. 72a), the secondary of the transformer being included in the circuit with a microphone M and a battery B. When a person speaks in front of the microphone, variations in voltage occur (through induction) across the terminals of the arc A, causing corresponding sudden changes of temperature in the otherwise steadily sustained D.C. arc. This means that the surrounding air in the room is subjected to sudden



FIGS. 72 F and G. Showing two circuits evolved by the Author primarily for photophonic transmission.

expansions and contractions, and the commotion thus produced is heard as sound. Corresponding variations also occur in the intensity of the light.

RÜHMER'S ARRANGEMENT.—Fig. 72b shows another modification, due to **Rühmer** (51), which does away with the necessity of a transformer and local battery.

In this case a microphone M and high resistance R are connected in series with one another across the arc.

Both Simon and Rühmer independently showed that an arc could be modulated (or voice-controlled) by placing a microphone M across an inductance I consisting of a few turns of wire placed in the supply leads (Fig. 72C), a sufficient number of turns being employed to give a drop in the voltage equal to 4 or 5 volts.

W. DUDDELL'S SPEAKING ARC.—In 1900 **W. Duddell**

(51), (52), (53), (56) showed an arrangement for modulating an arc in which he arranged a transformer T (Fig. 72D) in parallel with a D.C. arc. A condenser C, in series with the transformer, keeps the D.C. circuit open and prevents the current from the supply mains from passing through the transformer. Two chokes, X and Y, placed in the mains, in their turn prevent currents induced in the secondary circuit of the transformer (which pass without hindrance through condenser C) from travelling down the mains.*

A microphone may also be placed in the field circuit of the dynamo supplying the D.C. (50).

THE AUTHOR'S METHODS OF ARC MODULATION (1086).—The methods shewn in Figs. 72 F and G were devised by the **author** in 1924,† and were primarily intended for use in coupling up a wireless receiving circuit to an arc in order to control the latter for purposes of photophony ; but either of the circuits may be employed to amplify local microphone currents and operate a speaking arc or to act as a radio-telephonic relay.

Fig. 72F shows a method of resistance capacity coupling which was found to answer quite well. (A resistance to control the arc supply is, of course, necessary.) R may either be a resistance or a choke. C and D were connected to the secondary of an inter-valve transformer in the plate circuit of a wireless receiving set. U is a battery employed to increase the plate voltage of the valve, in addition to that already supplied to it by the electric light mains.

Fig. 72G shows a method of transformer coupling. The valve can be made to function at the correct place on its characteristic curve by means of a grid bias battery.

At this point we will diverge from the subject of Photophony and Speaking Arc Control Methods, and will return to it again at the end of the description of De Forest's gas flame microphone on page 135.

SIMON'S MICROPHONIC ARC.—In 1901 **Simon** showed an experiment before the Electro-technical Society of Berlin (50)

* The **author** experimented, in 1923, with the speaking arc as a loud speaker for broadcast reception (810).

† Reference should also be made to **O. Bothe's** method of thermionic valve arc modulation for recording sounds in a photographophone, and for sound reproduction by a speaking arc (reference 1089).

in which he used a D.C. arc as a transmitter, in place of a microphone. The arc was struck between two carbons, C and C_1 (Fig. 72E), in a parabolic cavity in a block B, and a trumpet T served to concentrate the sounds of a voice on to the arc.

PHILLIPS THOMAS' GLOW DISCHARGE MICROPHONE.*—During 1923 (59), (60) **Phillips Thomas,** of America, invented a device which he calls " the suspended glow discharge " microphone.

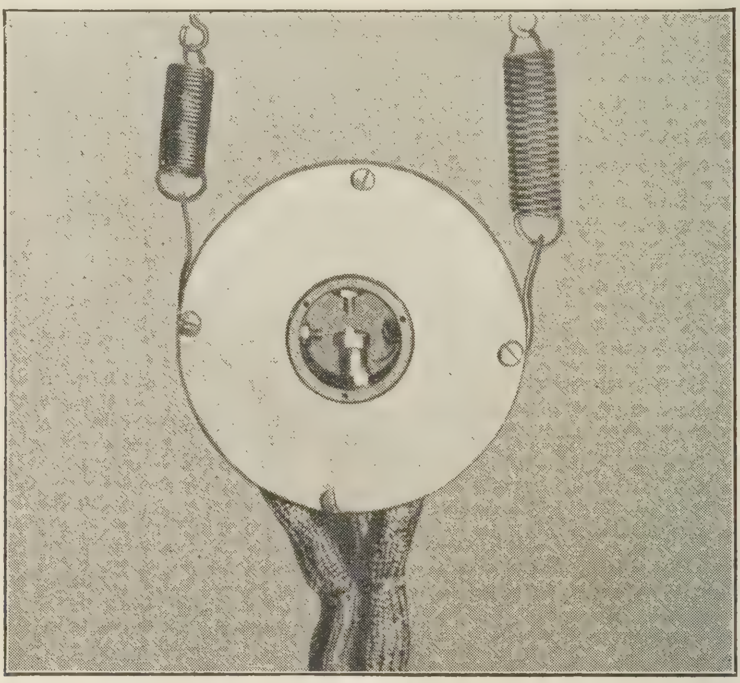


FIG. 73. In Phillips Thomas' Microphone, of which this is an actual reproduction, use is made of the properties of a glow discharge between copper electrodes.
(*With the permission of the "Wireless World."*)

Fig. 73 is a photographic representation of the actual microphone of Phillips Thomas.

Fig. 74B is a diagram illustrating the character of the D.C. glow discharge which takes place in air between copper electrodes in close proximity. A resistance is arranged in the arc circuit, which prevents the formation of a heavy current arc, and a glow discharge takes place, which, owing to the ionized condition of the air across the arc, carries a small current of some 20 milliamperes, at a voltage of between 300 and 1,000. This glow may be said to be made up of four portions —the anode glow, the anode column, the Faraday dark space,

* In 1924 the beating of the human heart was broadcast from the Westinghouse station at New York, KDKA by aid of a Phillips Thomas glow discharge microphone placed against the chest of a subject, and on this occasion the heart beats were heard in Europe (1055).

and the cathode glow. Fig. 74A shows the connections employed by Thomas when using this microphone.

Figs. 74 C and D show two types of microphone devised by Thomas. In the lower one, D, an exploring electrode is fitted to enable the portion of the glow nearest to the anode (the positive column) to be employed for connection to the amplifier, as the sensitiveness of the instrument was found to be almost entirely in the positive portion of the discharge.

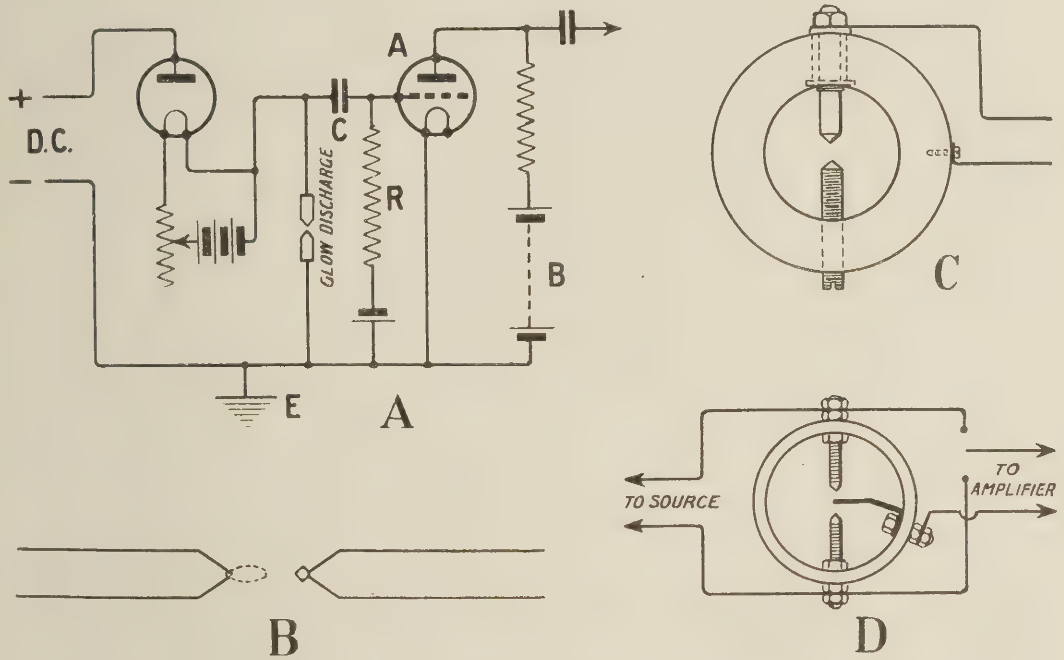


FIG. 74A. Shows the arc and amplifier circuits used by Thomas for his "Glow Discharge" Microphone, two types of which are illustrated at C and D. B illustrates the form of discharge obtained.

(*With the permission of the "Wireless World."*)

The use of the exploring electrode recalls to the author's mind an effect he noticed and recorded in 1910 (63). He found that if a pointed glass rod was brought close into the centre of the spark gap in an oscillating circuit, as used for wireless transmission, the white spark itself was attracted towards the glass, while a definite reddish glow could be observed on the side remote from the glass, which he took to be incandescent nitrogen. The presence of this rod produced a more and more highly pitched note as the rod was pushed further and further into the centre of the gap, and it also had an effect similar to an increase of voltage across the gap.

BLONDEL'S MANOMETRIC FLAME CONTROLLER.—Fig. 75 shows an arrangement employed by **Blondel** in 1902 in an endeavour to control a spark operated oscillating circuit

by the voice. Two spark rods or electrodes A and B are arranged in an oscillating circuit, and set just beyond sparking distance above a manometric flame F (54). When a person speaks in front of the mouthpiece M, a thin diaphragm D vibrates and alters the pressure of the gas supply, causing the flame to alter in length. The excursion of the flame into the gap between the electrodes alters its resistance, and sparks occur in response to its movements. Blondel patented this device in England and Germany in 1902 (253), (254), and (50).

Fig. 76 shows a very similar arrangement employed by **Chambers** in 1909 (255). G is a small platinum receptacle containing a volatile salt. This is held in the base of the flame

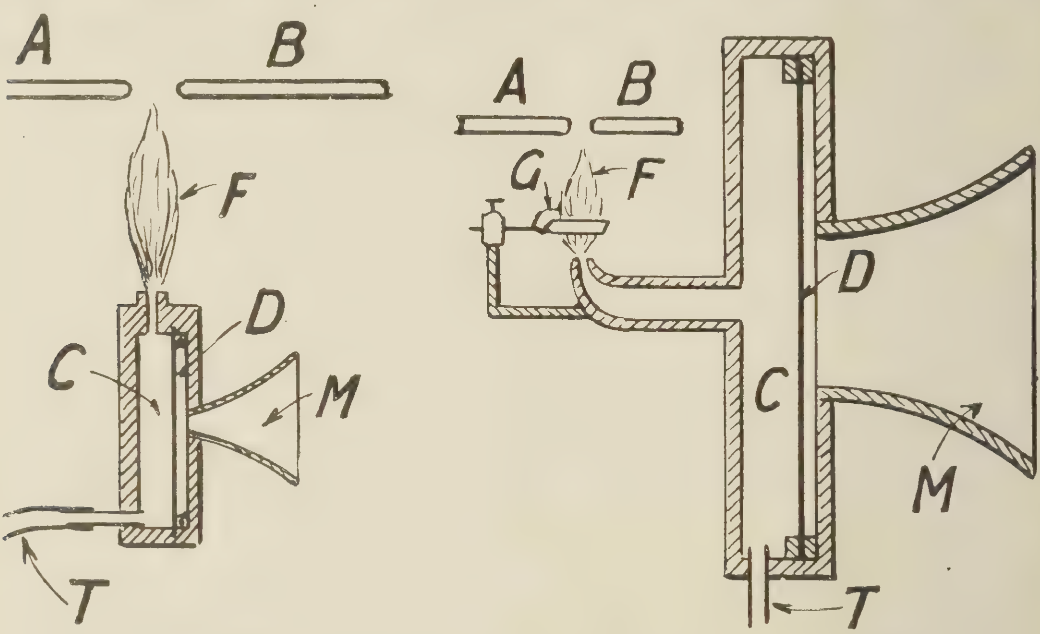


FIG. 75 (left). Blondel's arrangement, whereby the resistance of a spark gap is controlled by a manometric flame.

FIG. 76 (right). Chambers' more sensitive scheme, employing a volatile salt in the receptacle G.

in order to introduce extra ions and still further reduce the resistance of the gap between A and B.

FLAME AUDION.*—**Mearle Mellinger** in 1911 (279) described a flame audion for the reception of Hertzian waves in which a gas flame is ionized by a salt in much the same way as the above. Fig. 76A shows the arrangement which he employed. S is a Bunsen burner above which is supported a piece of copper wire gauze to steady the flame F. Two electrodes (marked + and — in the figure) enter this flame. The negative electrode at the base of the flame is a small platinum receptacle

*The flame detector was originally invented by Lee de Forest in 1903 (see pages 209 and 237 and British Patent 5258, 1906).

in which a suitable salt is placed in order to supply additional ions. The positive electrode consists of a short platinum rod or wire, and is supported just above the negative electrode (about 1/16in. distant). Aerial and earth connections are shown at Æ and E.

De Forest's Gas Flame Microphone.*—Another type of microphone invented by **Dr. Lee de Forest** should also be mentioned (65). Two heat-resisting electrodes are placed

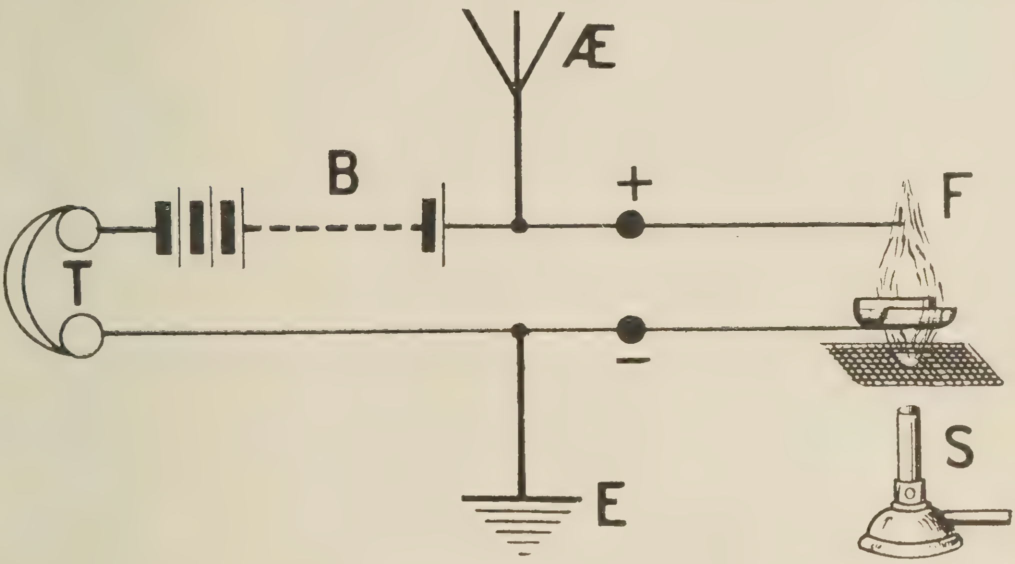


Fig. 76A. The connections employed by Mellinger for a Flame Detector in a receiving circuit.

in suitable relation to one another in a gas flame (or in an oxy-acetylene gas flame). If these electrodes are placed in a high voltage electrical circuit the flame in their neighbourhood is highly sensitive to the slightest sound, and changes of resistance occur between the electrodes in exact accordance with the sound waves.

Further Experiments in Photophony.—From 1902, and during the next two or three years, **Rühmer, Schuckert** (also many others) carried out a great number of practical and very satisfactory experiments in photophony on the Wannsee and the Havel, near Berlin, and later in the same year two permanent stations were erected, one at the works of Messrs. Siemens, Schuckert & Co., in Berlin, and the other at the parish school in the Baumschulweg, 2·5 kilometres distant. Speech was transmitted perfectly, both by day and by night, and even in wet weather, though the results were not so good

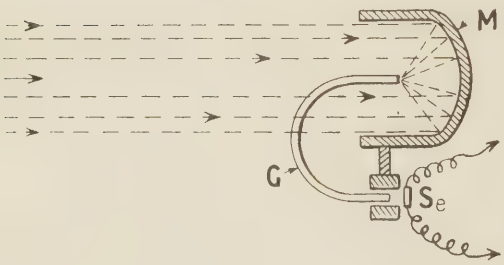
* For short account of De Forest's experiments with flames see Chapter XV.

in the latter case. Simultaneous conversations were also carried on in both directions, the two coincident beams of light from the searchlights not interfering one with the other.

More recently, in England, **A. O. Rankine** has carried out some experimental work in Photophony. See Ref. (722).

In France, in 1919, **E. Furet** patented a method of communicating with a train by means of light rays (726).

G. G. BLAKE'S PHOTOPHONE—TRANSMITTER AND RECEIVER (1086, 1087, and 1088).—In 1925 the **author** conducted some experiments in Photophony (described in a lecture to the Radio Society of Great Britain on April 22nd, 1925) in which rods of glass and silica were employed in conjunction with



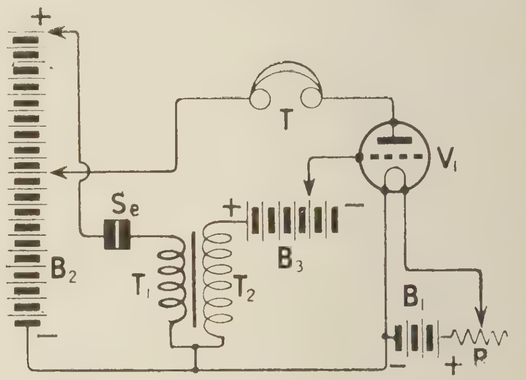


FIG. 77A (left). Illustrates the principle of the Author's Photophonic Receiver.

FIG. 77B (right). Transformer coupled amplification circuit used by the Author for photophonic reception.

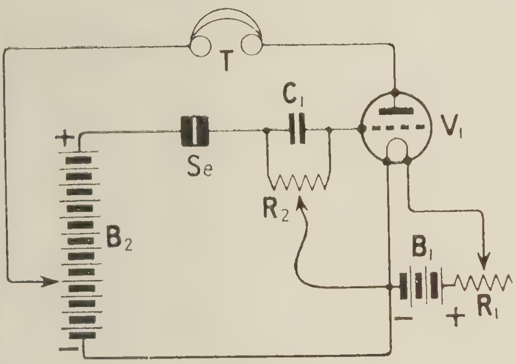
reflectors in the transmission and reception of a photophonic beam.

The principle is illustrated in Fig. 77A, which shows the arrangement used in reception. The received beam is focussed by a concave mirror M, or by a lens, on to the end of a curved rod G, and conveyed by the latter to a selenium cell Se. The rod, if made of clear silica with optically polished ends, transmits all but about 10 per cent. of the light, and filters out the heat which at the focal point of the mirror would rapidly destroy the selenium cell.

For transmission the same principle is employed. The source of light is focussed upon one end of a silica or glass rod, and conveyed round to the focal point of a concave mirror. The converse action takes place. The mirror, in

this case, collects and projects the light thus transmitted in the form of a parallel beam.

Figs. 77 B and C are the author's amplification circuits for photophonic reception. In case B the selenium cell is coupled to a triode valve by means of a transformer T_1 T_2. In case C resistance capacity coupling is employed. The special feature of this latter circuit is the employment of a slider on the high resistance R_2, connected across condenser C_1. By the movement of this slider a balance of adjustment can be obtained. The part of the resistance nearest to the grid functions as a grid leak and prevents the grid from accumulating to negative a charge, while the portion of the resistance nearest



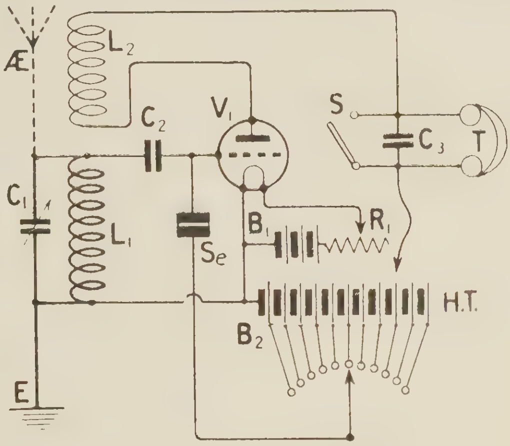


FIG. 77C (left). The Author's resistance coupled circuit for photophonic reception.
FIG. 77D (right). The Author's light-sensitive selenium cell (Se) control of oscillating cricuit.

to the selenium cell provides the necessary voltage drop in the selenium circuit to ensure that the grid side of the selenium cell is more positive than the negative terminal of the H.T. battery.

THE CONTROL OF HIGH AND LOW FREQUENCY OSCILLATING CIRCUITS BY MEANS OF VISIBLE LIGHT (1086 and 1088).—In his lecture, referred to above, the **author** described an oscillating circuit controlled by light. This is illustrated in Fig. 77D. A selenium or other light-sensitive cell can be placed between the grid of the valve and a tapping on the H.T. battery as shown, or it may be placed across the inductance, the reaction coil, or between the grid and reaction circuits.

The arrangement is so sensitive to light when employed as a transmitter, and heterodyned with an oscillating receiving circuit, that the unfocussed light of a candle at the distance of over 50 feet is sufficient to give a clearly appreciable change of the note in the distant receiver if anyone passes between the light and the selenium cell.

The circuit itself can also be employed as a receiver, and it can be caused to oscillate at an audible frequency.

The circuit is capable of many applications. It can be employed :

(*a*) For military, naval, and police purposes.*—Such a circuit, suitably disguised, could be placed in proximity to a light at a distance from a camp, building, or ship. The circuit would be set in oscillation and caused to heterodyne a wireless receiver at the camp. This arrangement would then act as an invisible sentry. Directly anyone passed between the selenium (or any other light-sensitive cell) and the light, or tampered with either, his presence would be indicated in the receiver at the camp by a change of note.

In order to prevent the light from the rising moon, or any other unwanted light, from acting upon the circuit, the cell can be placed in a long tube, with or without a lens at its orifice, which screens it from all light except that which is directed straight into the opening of the tube. Alternatively, two similar selenium cells in the different arms of a Wheatstone bridge may be employed—if a light falls upon both, equal and opposite effects are produced which balance out ; so that the total resistance of the grid circuit remains unchanged, and no effect is produced in the oscillating circuit. On the other hand, either cell operated separately by light would respond and cause the desired frequency changes.

(*b*) For cable telegraphy the circuit could be operated by very slight movements of light from a mirror galvanometer, and the beat note could be employed to cause a suitably tuned reed at the orifice of a resonant tube to vibrate, and this could operate a relay.

Considerable selectivity could be obtained by the employment of a plurality of such cells, etc. A number of messages might be transmitted, each on a different note frequency, and all notes be produced simultaneously on a loud speaker, and each separately recorded by its own suitably-tuned reed, relay, and recording instruments. Alternatively, the relay might be placed in the plate circuit of the receiving valve.

(*c*) On board ships in the vicinity of a lighthouse such an

*T. W. Case, in 1918, took out British Patent No. 132,341, covering the use of thallium and sulphur, and thallium and iodine cells, to control a circuit oscillating at audio-frequencies for harbour defence, but no suggestion was made of using the apparatus as a radio-transmitter, or of obtaining increased sensitivity by the heterodyne method.

arrangement would give a loud signal or change of note when the beam of light from the lighthouse passed across the field of view of the cell.

(*d*) To indicate the transit of a star across the field of view of a telescope.—In this case the selenium or other light-sensitive cell would be arranged at the eyepiece of the telescope.

(*e*) For photometric purposes, standardisation of candle-power, etc.—In this case a self-luminous screen coated with radium paint might be employed as a standard.

(*f*) The comparison and measurement of quantities of radium or other radio-active substance by measurement of the fluorescence they produced on a fluorescent screen placed in proximity to a selenium cell.

(*g*) The transparency of various objects to light could be compared.

(*h*) The density of various patients' bodies to X-rays could be measured, with a view to ascertaining the correct exposures in radiography.

(*i*) This method might also be applied to methods of distant control of airships, torpedoes, etc.

(*j*) Another possible application would be on the road, at dangerous corners, to give a loud howl when a motor passed, and so give warning to motorists of dangerous corners.

(*k*) It might also find application in systems of television.

(*l*) It is applicable also for heliographic and other forms of light signalling.

(*m*) It can also be used in methods for assisting the blind to realize the presence of light.

The Selenium Cell.—A great deal of research work has been done towards the perfection of the Selenium Cell, but as it lies rather outside the scope of this book the interested reader is referred to the following references: Minchin (369), Rühmer (300), Fournier d'Albe (298), (299), A. H. Pfund (304), W. S. Gripenburg (305), F. C. Brown (297), also (306) and (307), L. B. Crum (308), J. Kunz and J. Stebbins (309), G. W. Pickard (310), W. R. Cooper (313), M. J. Martin (314), Linder and Replogle (345).

See also References (50), (56), (89), (100), (108), (297), (299).

The reader should also refer to the work of **Prof. Minchin,** described in Chapter V. (pages 60, 61 and 62) of this book.

MONOCHROMATIC CELLS.—Monochromatic Cells (318), (319), (320), (724) have been produced which respond only to certain colours, so that it is now possible to transmit several conversations over one beam of light simultaneously. I quote the following from Dr. Erskine Murray's book, before cited: " If several searchlights are placed near one another at the sending station, each being provided with a light filter of different colour, their beams will blend in the atmosphere, and if the colours have been properly chosen will produce a beam of white light at the receiving station. The light will therefore appear to be radiating from a single uncoloured searchlight. If, now, each searchlight is separately acted upon, conversations transmitted simultaneously from the sending station may again be separated at the receiving station, if a number of corresponding receivers be used each of which is sensitive only to one of the colours transmitted. If an ordinary selenium cell were used, a confusion of all the voices at once would be heard."

THE THALOFIDE CELL.—About four years ago, the " Case " Research Laboratory, of New York, placed an entirely new cell, invented by **T. W. Case** (322), (723), (976), upon the market, called the " Thalofide " photo-electric cell. It is claimed that the electrical resistance of this new cell is reduced 50 per cent. on exposure to a light of 0.06 of a foot candle from a tungsten filament source, and that its response is more rapid than is the case with a selenium cell (58).

ANTIMONY SULPHIDE CELL.—In 1907 **Prof. F. M. Jaeger** (101) discovered that natural sulphide of antimony showed a very strong alteration of its electrical conductivity under light radiation. Its " inertia " after radiation was smaller than that of selenium, and its maximum effect was obtained in another part of the spectrum. **Wm. Sebastian Gripenberg** describes the manufacture of an antimony sulphide cell by himself and **Prof. Jaeger,** and experiments therewith, in Ref. (102).

OTHER FORMS OF LIGHT-SENSITIVE CELL.—**A. H. Pfund** has shown that copper oxide is sensitive to light (311).

J. Elster and **H. Geitel** have constructed potassium photo-electric cells (316).

In 1916 **J. Stebbins** (108) described a cell which is particu-

larly sensitive to ultra-violet light. It consists of a liquid alloy of sodium and potassium in an exhausted tube.

The alloy forms one pole, which is connected to the negative pole of the battery. The other pole is above the surface of the alloy, and insulated. When placed in a beam of ultra-violet light, the alloy emits electrons and the cell becomes conductive.

P. H. Geiger has shown (818) the photo-electric properties of argentite.

Soot has also been employed (56) in the manufacture of light-sensitive cells, but is only very slightly sensitive.

Murdock (730) has shown that certain electrolytic cells are photo-active.

The "Polyphos" Light-sensitive Cell (882).—Sodium, potassium, or rubidium is contained in a glass tube either exhausted or containing hydrogen gas. The cell contains two electrodes, one connected to the sodium and to the negative terminal of a small battery, the other electrode being connected to the positive terminal of the battery. Light falling on the sodium causes it to emit electrons and so vary the resistance of the space between the electrodes.

Rubidium Cell (in Neon) (108).—Hydrides of alkali metals when placed in neon or hydrogen are sensitive to light. The rubidium-hydride cell in neon is particularly sensitive, and responds almost exactly proportionately to the incident energy in the illuminating beam of light.

Other References.—For other references re photo-electric cells see (723–725), (730).

Secret Photophonic Transmissions.—By using one microphone to control two arcs the beams from which are intermingled, and by so arranging the circuits that with each sound the light from one arc is increased while the light from the other is diminished to an equal degree, equal and opposite variations are obtained, the total effect of which upon the receiver will be nil.

If, now, two complementarily coloured filters are placed in the path of the beams, the resultant light received on an ordinary selenium cell will be white, and will be ineffective ; but if a monochromatic cell, sensitive to one only of the complementary colours* be employed for reception, it will respond

* For colour-sensitive photo-electric cells see Ref. 724.

at once. By using two receivers their actions may be superposed in the same direction on a telephone line common to both circuits, Only the person called who knows the exact wavelength (colour) used can hear the voice in undiminished loudness, while no one else, in spite of the fact that his sensitive cell is illuminated, can receive anything (50).

Larsson and Svalling's Light-operated Relay.—In 1908 **G. O. Larsson** and **G. E. Svalling** (872) invented an ingenious device, to act as a relay, operated by a beam of light. It is a form of " radiometer," and consists of a delicate pivot in the centre of an exhausted vessel. Balanced on either side of it are a blackened vane and an iron rod. When light is directed on to the vane it is repelled, and the iron rod is brought into contact with a contact pin and so is made to complete a local circuit. The rod and vane are adjusted by a light spring, or by the attraction of a small magnet placed in a suitable position outside the tube.

In 1912 **K. Ort** and **J. Reiger** (323) showed a method of modulating the light emission from an incandescent electric lamp. (See also Ref. 978 for details of the researches of **Bragg** and **Rankine.**)

In September 1923 a demonstration of Photophony took place at Liverpool, on the occasion of the meeting of the British Association, when music was transmitted from St. George's Hall and conveyed on a beam of light to the Technical School.

The Photographophone (an instrument to record music and speech on a photographic film).—Before leaving the subject of Photophony, the photographophone should be mentioned. This instrument was invented by **Rühmer** in 1901 (80), and exhibited by him at the Berlin Polytechnic Society in 1902. A detailed description of the apparatus, with photograph, is given in Dr. Erskine Murray's translation of Rühmer's book (50). The following brief description of the instrument, and a suggestion by the **author** of its possible future uses in conjunction with wireless, were given by him in a lecture to the Wireless Society of London at the Royal Society of Arts in 1920 (79) (before the introduction of broadcasting):

" May we not confidently look forward in the near future to a much wider use of wireless telephony ? I foresee a time

when it may be the general custom for us to receive our daily news in the morning while breakfasting, by wireless telephone.

"With a small frame aerial, an amplifier, and a loud-speaking telephone, we may hear our news from powerful telephony stations. I see no reason why photographophonic records could not be taken of public speeches, important lectures, etc., by making use of Rühmer's photographophone.

"All public platforms could be fitted with microphones (much as they are now with the electrophone). These microphones would be used to control a speaking arc (A, Fig. 78A), or a manometric flame the light from which is photographed upon a photographic film (F.). When developed, this film would be of uneven density, corresponding accurately to the variations in the intensity of the light as controlled by the

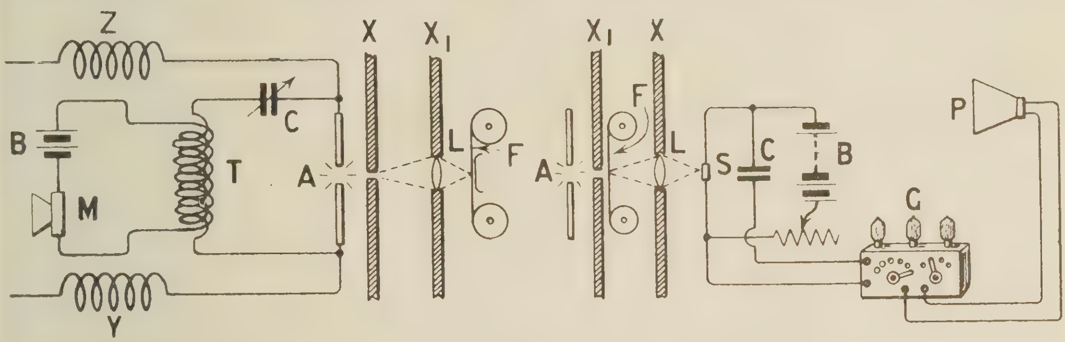


FIG. 78A (left). Diagrammatic representation of Rühmer's apparatus for obtaining a photographic record of a speech.

FIG. 78B (right). Rühm(er's Apparatus for reproducing the speech from the "light" picture. To which valve amplification has been added).

voice. The film could then be sent to the wireless transmitting station, where it would be passed in front of a steady source of light (as shown in the diagram for Rühmer's reproducer, Fig. 78B), the variations of light thus produced being focussed upon a selenium cell. The corresponding current variations, passing through this cell, could then be amplified by a series of thermionic valves, and employed to modulate the radiations from the aerial of the transmitting station.

" Thus people would hear not only the news, but also the actual speeches, delivered word for word in the voices of the original speakers. Such photographophonic records would be far more reliable than shorthand notes. To carry this dream one step further, we could imagine all the speeches from, say, the Houses of Parliament transmitted on one fixed wavelength, and other fixed wavelengths allotted to other important institutions ; so that, as one sat at breakfast, he could

turn a switch on to a stud marked 'Houses of Parliament,' 'Albert Hall,' etc., and select that portion of yesterday's news he wished to hear.

"Should such a system become universal, I foresee a time when a room is set apart in such an institution as this (the Royal Society of Arts) where photographophonic records of important lectures that have been delivered during the week in all parts of the world are redelivered, either by wireless from transmitting stations or by reproduction directly from the film, by using a selenium cell, etc., in the lecture room. This, together with a cinematographic reproduction of experiments given at the lecture, synchronized with the speech film, should give a most lifelike representation. The synchronization of the photographophonic film with the cinematographic film would open up great possibilities to the film producer. It would enable plays to be reproduced, not only in dumb show, as at present, but with words also. The nearest approach to this at present is, I believe, the synchronization of the gramophone with the cinematographic film. One objection to this arrangement is the small size of the record; a photographophonic film could, of course, be of any desired length.

"Quite recently the Case Research Laboratory of New York has placed upon the market the Thalafide cell. It is claimed that the resistance of this cell is reduced by 50 per cent. on exposure to a light of 0·06 of a foot candle, from a tungsten filament source, and that its response and recovery is more rapid than is the case with a selenium cell. If what they claim for it is true, the use of this cell in place of selenium should bring my dream a good deal nearer to realization."

The author's predictions of 1920 are already being fulfilled. In America the photographophone has reappeared in greatly perfected form, under the new name of the Pallophotophone. An account of this instrument was given before the American Institute of Electrical Engineers in 1923.

By means of this instrument speeches in different languages have been faithfully recorded on films, and afterwards the films have been employed to modulate the transmission from a broadcasting station, exactly as predicted. The following is a quotation from Mr. Hoxie's paper (82) and (84): "It might be well to state that comparisons have been made many

times between the effects produced by talking directly into the transmitter and a reproduction of the same by means of the film record. This has been done by connecting the apparatus with an amplifier and loud speaker [the **author** suggested the possibility of valve amplification in his 1920 lecture], and first varying the light by means of the voice direct and immediately producing the same words by means of a record previously made ; and it has been impossible even for experts to note any difference between the two."

Mr. Hoxie goes on to say how the film records have been used for broadcasting, and how by passing the film record in front of a steady source of light, it is made to control a photo-electric cell (similar to the Case cell to which the author drew attention), connected in the grid circuit of the modulation valve of the broadcast transmitting station (this direct valve-control was also predicted by the author). This does away with the necessity of first converting the light variations into sound, and then causing the sounds to operate the usual transmitting microphone.

A lecture by Dr. William Gates on the language of the ancient Mayas was thus recorded (which included phonetic sounds in many languages), and broadcast by the General Electric Company from their broadcasting station WGY at Schenectady.

On New Year's Night in 1922 similar records were reproduced of a talk by Dr. Gates, followed by a reading by Cipriano Alvarado, a full-blooded Kuiche Indian, in his own tongue. Dr. Gates, who is an authority on language, was listening to this speech and reading by the Indian on the radio, some miles distant, and stated that the reproduction was perfect, in spite of the foreign articulation.

In 1901 **Prof. J. G. McKendrick** and **Dr. J. Erskine Murray** exhibited a very similar instrument for the photographic recording and reproduction of sound at Nottingham. A reference to this apparatus is made in Dr. Barton's text book on sound. **C. W. C. Wheatley** also claims to have carried out experiments on the same lines (81). About 1920 **Dr. Rankine** exhibited a photographophonic record from which he reproduced words at a Royal Institution conversazione, and he has since carried out further experiments.

M

At the end of his 1920 lecture the **author** suggested the great possibilities before the film producer in the synchronization of the photographophonic film with the cinematographic film. In an article in " Wireless Weekly" of July 4th, 1923 (83), Mr. C. F. Elwell states that a method has been perfected by **Dr. de Forest** for such synchronization and is called the "phonofilm." The standard cinematograph film is used, the sound record occupying a very narrow strip on its margin, about 3/32 of an inch wide.

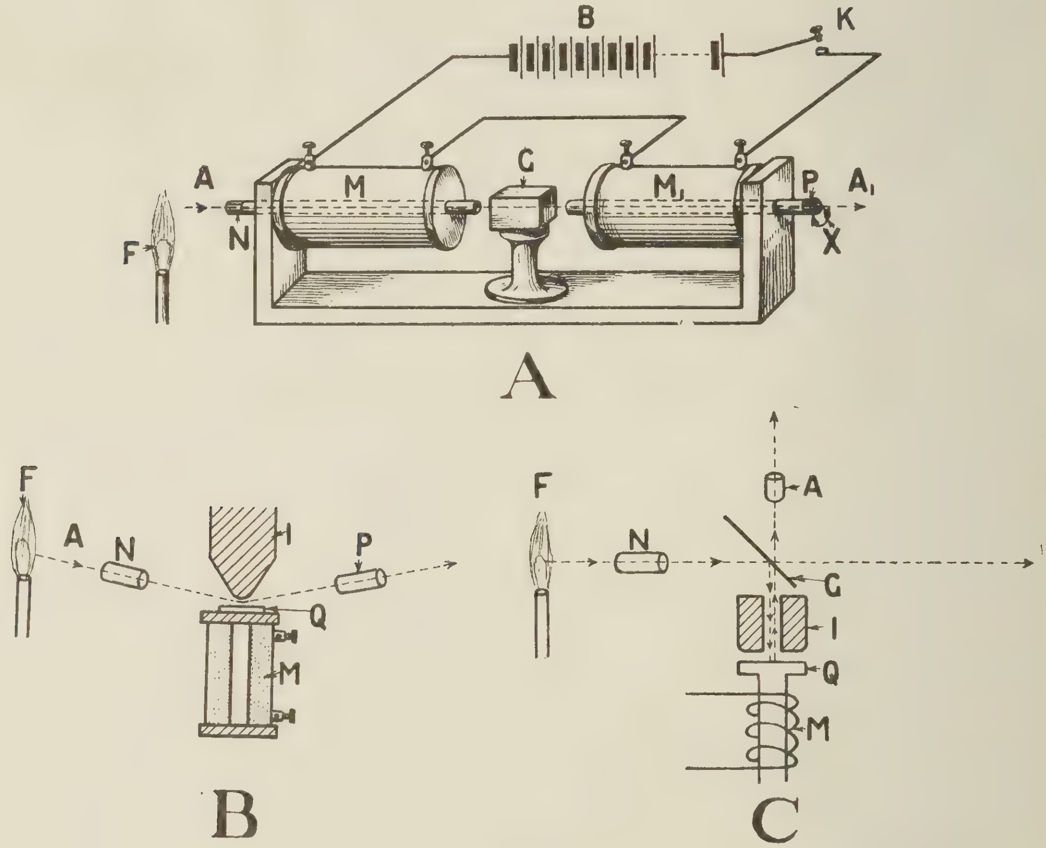


FIG. 79A. A suitable apparatus for demonstrating the effect noticed by Faraday when a beam of plane-polarised light passes through some transparent substance placed in a strong magnetic field.

Figs. 79B and C illustrate two of Kerr's arrangements for producing a similar effect.

As demonstrated in London, the process seems to be practical and commercial, so that any cinema can easily be equipped. These films have been shown, and their songs and speech reproduced, at the Finsbury Park Rink Cinema, the Tivoli, and other places.

THE FARADAY EFFECT.—Before we pass on to other methods of Radio-Telephony we should mention tbat use has been made of the " Faraday Effect " for the control of a beam of polarised light for photophonic transmission. Very little use

has been made of this form of modulation in practical photophony up to the present, but there are probably great possibilities in this direction. The method is based on the "Faraday Effect." There are three known ways in which a beam of light can be directly affected by a magnet.

In 1845 **Michael Faraday** showed that if during the passage of a beam of plane-polarised light through a transparent medium the latter is placed in a powerful magnetic field (the direction of the lines of force being in the same direction as the light), the beam is rotated.

Fig. 79A shows the apparatus necessary for demonstrating this effect. The arrows A, A_1 represent a beam of light from a flame F, or other steady source. After it leaves F the light passes through a Nicol prism N, and is thereby polarised. It then passes through a hole down the centre of the poles of an electro magnet M, M_1, on its way passing through a block of glass or other transparent substance G (a greatly increased effect is obtained by the use of carbon bisulphide (108)). After passing through the centre of the second magnetic pole M_1 it goes through a second Nicol prism or "analyser" P. The analyser P can be rotated as indicated by arrow X. In one position the light passes through it at its full intensity; but as the analyser is rotated the light diminishes in strength until P is at right angles to the Nicol prism N. When this point is reached the light is completely cut off.

If key K is now depressed, and a powerful magnetic field is created across the transparent material at G, the plane of polarisation is rotated, and while the current is passing through the windings of the magnet the light again becomes visible.

Verdet (1) showed that the amount of this rotation was proportional to the strength of the field and the length of the transparent object or trough of transparent liquid. When used for photophony a suitable microphone is placed in circuit with the coils of the magnet in place of the key K.

The Kerr Effect.—The second method of rotating a beam of plane-polarised light was shown by **Kerr** in 1877.

In Fig. 79B, M is an electro-magnet. A beam of plane-polarised light impinges obliquely on the highly-polished iron pole-piece Q, and, glancing off from its surface, is examined by means of an analyser P. If the latter is rotated to the

position in which it becomes opaque to the polarised beam, on passing a powerful current through M the light again becomes visible, indicating that the plane of polarisation of the reflected ray of light has been rotated. I is a mass of soft iron, brought as nearly in contact with the pole of the magnet as may be, only just allowing sufficient space for the light to pass below it. The presence of this iron pole-piece increases the effect materially.

Fig. 79C shows Kerr's arrangement for rotation of a beam of polarised light at perpendicular incidence. F is the source of light, N a Nicol prism, I a soft iron pole-piece almost in contact with the pole Q of the electro-magnet M. G is a sheet of glass which reflects part of the polarised beam down vertically on to the polished pole-piece Q. Thence it is reflected up through G and examined by means of an analyser A.

Kerr found (1) that in this case the plane of polarisation was rotated in a direction exactly opposite to the direction of the current through the magnet coils M.

THE ZEEMAN EFFECT (1).—The third method is that of **Zeeman,** who showed, in 1896, that the D lines of the spectrum are changed in appearance if the light is passed through a powerful magnetic field.

THE APPLICATION OF ULTRA-VIOLET RAYS TO RADIO-TELEGRAPHY.—As already mentioned, between 1887 and 1888, in the course of his investigations, Hertz showed that if ultra-violet light were allowed to fall on the spark-gap of his resonator it became more sensitive, and its sparks showed up more brightly, and that while under the influence of the ultra-violet radiations, the spark (from a given voltage) would bridge a gap impossibly long under normal conditions.

SIGNALLING WITH ULTRA-VIOLET LIGHT.—In 1898 (4A) **Professor Zickler** succeeded in signalling, by means of a beam of ultra-violet light, to a distance of 200 metres, and predicted that, with suitable lamps and reflectors, here was a practical means of telegraphing over considerable distances.

The following is a short description of the method he adopted : For transmission he employed an arc lamp, rich in ultra-violet rays, provided with a shutter and quartz lens for directing flashes towards the receiving station, where they were brought to focus (by either a large quartz lens or a

reflector), upon the spark-gap of a small Hertz oscillator with its spark knobs separated just beyond sparking distance. When the signalling took place, the ultra-violet rays ionized the air between the spark knobs and allowed sparks to pass, giving rise to Hertzian waves, which acting on a coherer, operated a telephone or Morse instrument.

(Warburg, Kreussler, Sir J. J. Thompson, and others have also studied the ionizing effect of ultra-violet rays (40).)

ZICKLER'S ULTRA-VIOLET DETECTOR.—In 1898 (50) **Zickler** made a detector for ultra-violet radiations which consisted of a small platinum plate placed at an angle of 45 degrees (similar to the anode of an X-ray bulb), and at a short distance from the centre of this plate he placed a small metal ball. These two electrodes were sealed into a glass bulb fitted with a quartz window, through which the ultra-violet rays could be focussed on to the negative electrode. The bulb was exhausted to a pressure of about 200 mm. of mercury. He found that this detector was much more sensitive than an ordinary spark-gap in air in responding to ultra-violet rays.

SELLA'S ULTRA-VIOLET DETECTOR.—**Sella** employed a detector similar to this connected to a high-tension supply, and a telephone for wireless telephony in conjunction with a photophonic transmitter.

Dussaud carried out experiments with ultra-violet rays, using a fluorescent screen, placed near to a selenium cell, which acted as a detector. When the rays are brought to focus on the screen it fluoresces, the light which it emits alters the resistance of the selenium cell, and the sound-waves are reproduced in a telephone connected in circuit with the selenium cell and a battery.

WAR-TIME ULTRA-VIOLET SIGNALLING.—During the Great War use was made again of the ultra-violet radiations for signalling purposes. A most interesting paper was given before the London Physical Society on March 14th, 1919, by **Prof. R. W. Wood*** (see "Proceedings of Physical Society," vol. xxxi., Part IV.), entitled "A Demonstration of the Uses of Invisible Light in Warfare."

After a description of the use of a 6-volt electric lamp, hidden in the interior of a telescope, which was specially

*A résumé of the work of Case, Coblentz, and Wood is given in Reference 723.

arranged so as to transmit only an exceedingly narrow beam of light, visible only in the vicinity of the objects viewed through the telescope, the lecturer described how further secrecy was insured by placing a red filter in front of the lamp, so that only red rays were transmitted. The light was then invisible to the distant observer, unless he was provided with a similar red screen to cut out the daylight, when he could read signals to a distance of at least six miles. By night a screen of special " Chance " glass* was used, which transmitted only the invisible ultra-violet rays and cut out practically all the visible light, and the observing telescope was fitted with a small fluorescent screen on which the received rays were brought to focus. Its range was also about six miles.

Much use of ultra-violet rays was also made by the Admiralty for convoy work during the war.

In this case, a vertical Cooper-Hewitt mercury vapour arc was screened by a tube of " Chance " glass, which only transmits one of the mercury spectrum lines, which have a wave-length of ·3660 Ä.U., well beyond the visible spectrum.

When viewed from near at hand the arc appears to be of violet tint, due to the fluorescence of the retina, and a sort of foggy appearance is also seen, due to the fluorescence of the lens of the eye itself. This fills the whole field of vision, and nearly any object brought close to the arc will fluoresce more or less brilliantly in one colour or another. Uranium glass fluoresces a rich apple green, tallow glows bright blue, the human hand a faint purple, butter and margarine fluoresce differently. Live teeth fluoresce brilliantly, while false teeth remain unilluminated.†

All the above effects of fluorescence can be very easily carried out by placing a small piece of " Chance " glass in front of the lens of an ordinary magic-lantern illuminated by an ordinary electric arc. When signalling by means of ultra-violet rays from a mercury arc at sea the received rays are focussed by a lens on to a fluorescent screen made of platino-cyanide of barium (as used in X-ray fluoroscopy). The spot of green fluorescent light produced thereon is easily observable over a distance of four miles, and, says Professor Wood,

*Made by Messrs. Chance Bros., of Birmingham. Similar screens are also made by Messrs. Zeiss, and by the Wratten Department of the Kodak Company (66) ; and also by Dr. Gage, of the Corning Glass Works, N.Y. (105).

†The author reproduced these effects of fluorescence at his inaugural lecture to the Associate Section of the Radio Society of Great Britain in 1923 (90).

"has proved invaluable for keeping the ships of a convoy together in their proper relative positions at night."

ULTRA-VIOLET SIGNALLING IN AMERICA.—Similar researches and applications of ultra-violet rays were carried out in America by **Lewis Bell** and **Norman Marshall,** of Boston, a few months prior to the entry of America into the Great War (105).

The U.S. Army in France used an ultra-violet signalling lamp with a fluorescent receiver (331).

THE X-RAYS.—The use of Röntgen rays has even been suggested in connection with Radio-Telegraphy, but, as pro-

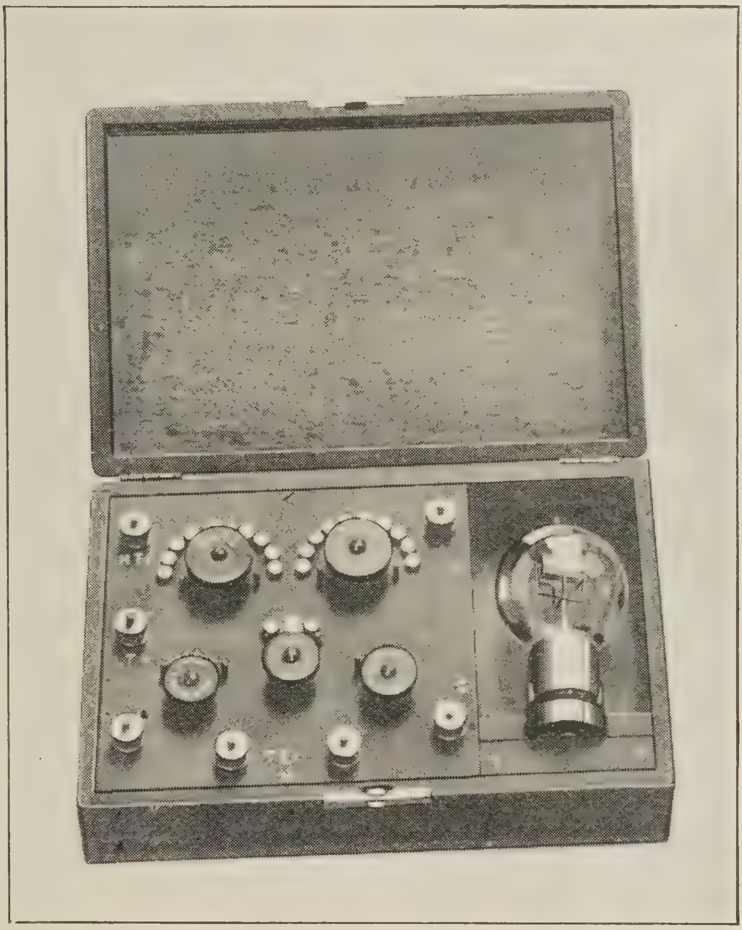


FIG. 80. An X-ray photograph of this wireless receiver, taken by the Author, is shown on the next page.

longed exposure to these wavelengths is extremely dangerous to life, it is unlikely that any practical development will take place in this direction.

HEINICKE'S METHOD OF X-RAY TELEPHONY.—In 1907 **Heinicke** patented a device (50) and (245) for the transmission

of speech. He places a sensitive spark-gap, similar to that invented by **Zickler** in 1898 (described earlier in this chapter), in series with an ordinary spark-gap, condenser, and inductance (coupled to an aerial), and he influences the sensitive spark-gap directly by means of X-rays, controlled by sound-waves. The source of X-rays is an X-ray tube having only one terminal. The author has not been able to find any published account of results obtained, and the scheme does not appear to be practical.

Radiography Applied to Wireless.—X-rays have been pressed into the service of Radio-Telegraphy in their legitimate direction. The **author** was, he believes, the first to employ them for the radiography of wireless sets, for illustrative and fault-searching purposes. Photographs of a wireless

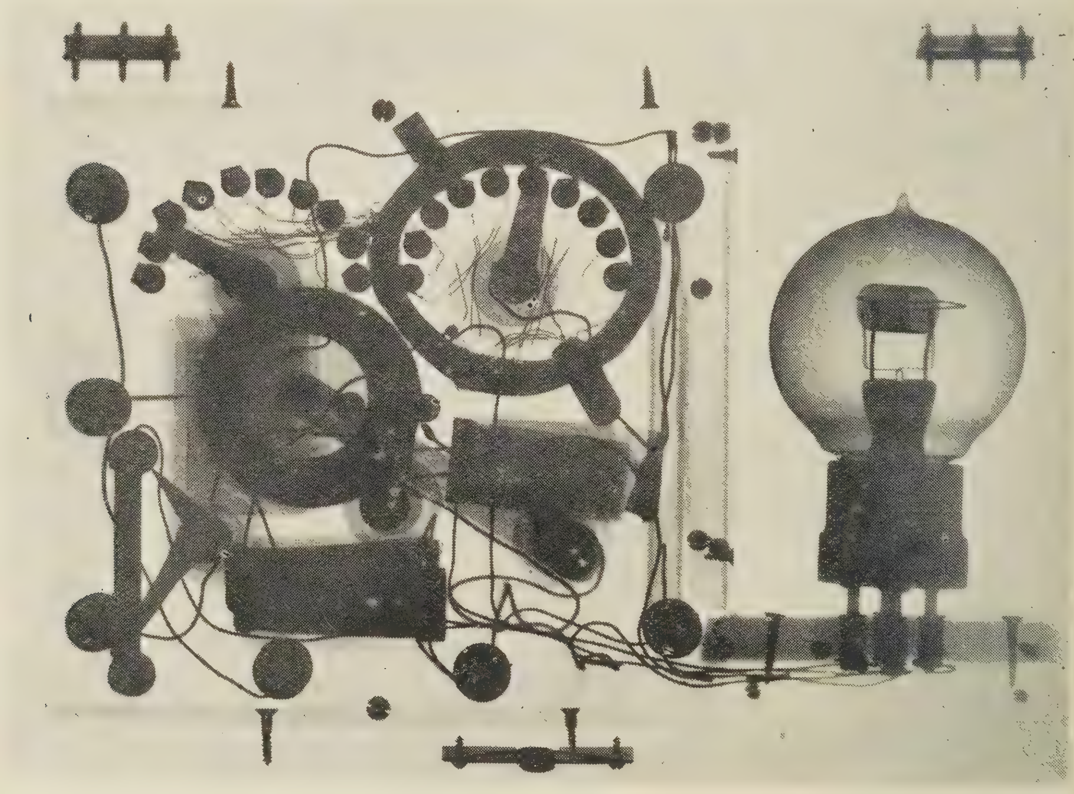


Fig. 80A. Various parts of the wireless receiver shown on the previous page can be recognised in this X-ray photograph.

set, taken in 1919 (see Figs. 80 and 80A), were employed by him to illustrate a lecture to the Wireless Society of London in 1920 (79).

The Employment of Infra-Red Rays for Signalling.—The infra-red rays have also been employed for signalling purposes (see References (723), (727), (728), (729), (1007)).

T. W. CASE.—In 1918 **Case** patented a method of Harbour Defence (976).* The arrangement is to place a searchlight on one side of the harbour mouth. In front of this a screen of smoked glass is placed to cut out the visible rays and transmit only the infra-red. This invisible beam is directed across the harbour mouth and focussed on a selenium cell, or, preferably, a cell formed of a compound of thallium and sulphur, which is particularly sensitive to the infra-red rays. The sensitive cell is connected in the circuits of a 3-electrode valve, the latter being arranged to generate oscillations of audible frequency and produce a definite note in a receiving telephone, dependent on the resistance of the cell. If a ship or other large object crosses the beam a change of note is heard, which acts as a signal.

L. A. CHARBONNEAU.—In the same year **Charbonneau** applied for a British patent (1007) to cover a method of signalling by infra-red rays from an incandescent lamp or other source. At the receiving end, an endless band coated with fluorescent zinc sulphide moves across the centre of focus of a receiving reflector. The infra-red rays transmitted wipe out the fluorescence of the zinc sulphide (excited locally by a small lamp), and produce dark spaces on the moving band representing dots and dashes. These can be read through an eyepiece, or recorded photographically.

SUBMARINE SIGNALLING WITH ULTRA-SONIC SOUND-WAVES

ULTRA-SONIC SOUND-WAVES.—In 1923 **M. Langevin** delivered a lecture before the Marine Academy on the Employment of Ultra-Sonic Sound-Waves for Submarine Signalling (230). These sound-waves are above the range of audition, and, so far, have proved to be the only reliable means of signalling under water. Hertzian and light waves will only penetrate to quite short distances through water, owing to absorption. The sound-waves employed by Langevin have a frequency of between 30,000 and 100,000 per second, and are emitted in the form of a beam for directive signalling.

The apparatus employed for the detection of these ultrasonic sound-waves depends upon the **Piezo-Electric Properties of Quartz,** discovered by the brothers **J.** and **P. Curie** in 1880 (231) to (234). They showed that, given a suitably cut plate of quartz, it would, if subjected to a mechanical strain, exhibit

* See also G. G. Blake's method of controlling an oscillating circuit by visible light radiations, earlier in this chapter ; also references 1086–1088.

equal and opposite electrification on its two surfaces, *i.e.* an E.M.F. is generated when the quartz is placed under tension. When ultra-sonic sound-waves impinge upon such a quartz plate, submerged below the surface of water, it becomes the generator of feeble electrical oscillations, which can then be amplified and detected by ordinary wireless methods.

Conversely, a quartz plate is employed by Langevin to produce ultra-sonic waves in water. When connected to a high-frequency generator it converts the electrical oscillations into mechanical vibrations of the same frequency.

THE PIEZO-ELECTRIC PROPERTIES OF OTHER SUBSTANCES (1071).—The piezo-electric properties of substances other than quartz have been made use of in connection with wireless.

The Western Electric Company, of America, employ Rochelle salt. If a crystal of this material is twisted slightly its two ends become positively electrified, and its centre develops a negative polarity. A potential difference of from 200 to 300 volts is obtainable with quite a moderate force.

Only a very small amount of electrical energy is, however, obtainable, as the crystal has a very high resistance.

E. Kilburn Scott demonstrated the properties of Rochelle salt at a meeting of the Faraday Society on July 22nd, 1921; and on July 23rd, 1921, **P. R. Coursey** (251) gave a demonstration to the Wireless Society of London, when he employed a Rochelle crystal as a gramophone reproducer. The passage of a needle attached to a crystal over the surface of a gramophone record imparted varying strains to the crystal, causing corresponding variations of voltage across it.

The crystal was connected to a 3-valve amplifier and a loud speaker, which rendered the results audible to the audience.

At this demonstration the Lecturer said: "Theophrastus, about 300 B.C., referred to Piezo-Electricity; and I have a date of 1703 when some Dutch chemists described the Piezo phenomena, etc. Anyway, we are fairly safe in describing it as 200 or 300 years old, and probably a great deal more."

CADY'S QUARTZ WAVELENGTH STANDARDS (1065), (1091), (1096), (1100).—**Cady**, working at the University of Middleton, Connecticut, makes use of another peculiar property of quartz crystals.

If quartz is cut with its length perpendicular to the axis and two opposite faces of the crystal, it is found to possess the curious property of ability to oscillate electrically at one definite high frequency, almost entirely independent of temperature variations or the thickness of the crystal.

The length of the crystal in millimetres approximately gives the wavelength of the H.F. oscillation in metres.

In use the crystal is placed loosely between two metal supports, across the variable condenser of a heterodyne wave-meter. When the latter is tuned to a frequency the same as the natural frequency of the crystal, the latter oscillates.*

The crystal may also be employed across an oscillating circuit coupled to the wave-meter.

Another use for the crystal is to employ it as a coupling between two stages of an amplifier.

Quartz crystals have more recently been employed to control the frequency of radio-transmitting stations.†

* See also reference (1124). "Luminous piezo-electric resonators."

† Reference should also be made to D. Eccles' "Master oscillator" patents: see footnote below page 349 of the appendix.

CHAPTER XI.

"Spark" and "Arc" Generators of High-frequency Currents for Transmission

THIS chapter opens with the description of various methods of spark excitation and gradually leads on to the various forms of arc generators. A definition of the "spark," in contradistinction to the "arc," may be helpful at this point. Some of the systems lie on the very borderland between these two phenomena, and it is often difficult to decide at a cursory glance which phenomenon is involved.

In the case of a "spark" generator of high-frequency currents no energy is taken from a supply circuit during the excitation of the oscillatory current, consequently the oscillations rapidly die out. In the case of an "Arc" Generator, energy is taken from the supply circuit during one half of each cycle of the high-frequency current.

According to **Dr. Eccles** (92), owing largely to the work of **Barkhausen** and **Blondel,** three types of arc have been observed, and they are distinguishable one from another as follows :

"(*a*) The maximum value of the oscillatory current may be so much less than the steady current that the arc is not extinguished. This is the case with the musical arc first described by Duddell.

(*b*) The discharge current from the condenser may be so large as to extinguish the arc at an instant near the maximum of the oscillatory current, as is the case usually with the Poulsen arc.

(*c*) The oscillatory current may often extinguish the arc and kindle it in the direction opposite to the steady current. This is exemplified by the 'quenched spark' with the 'ordinary spark.'"

It is interesting to note that the electric arc itself was shown for the first time at the Royal Institution in 1810, by **Sir Humphry Davy,** *i.e.* no one previous to this appears to have shown the sustained electrical arc occurring between two carbons first placed in contact and then slightly separated.

SPARK TRANSMITTERS

Much work has been done towards the perfecting of "Spark-transmission" since Marconi first placed a Righi exciter (or oscillator) between his aerial and earth. Lodge (as has already been described in Chap. VIII.) showed the

principles of electrical resonance in 1889, and enabled the Radio engineer to radiate waves of one definite and predetermined length. It was then felt that the action of the spark gaps themselves should be capable of much improvement.

ELIHU THOMSON'S MAGNETIC "BLOW-OUT."—In 1892 **Elihu Thomson** (94), (124) suggested the employment of a

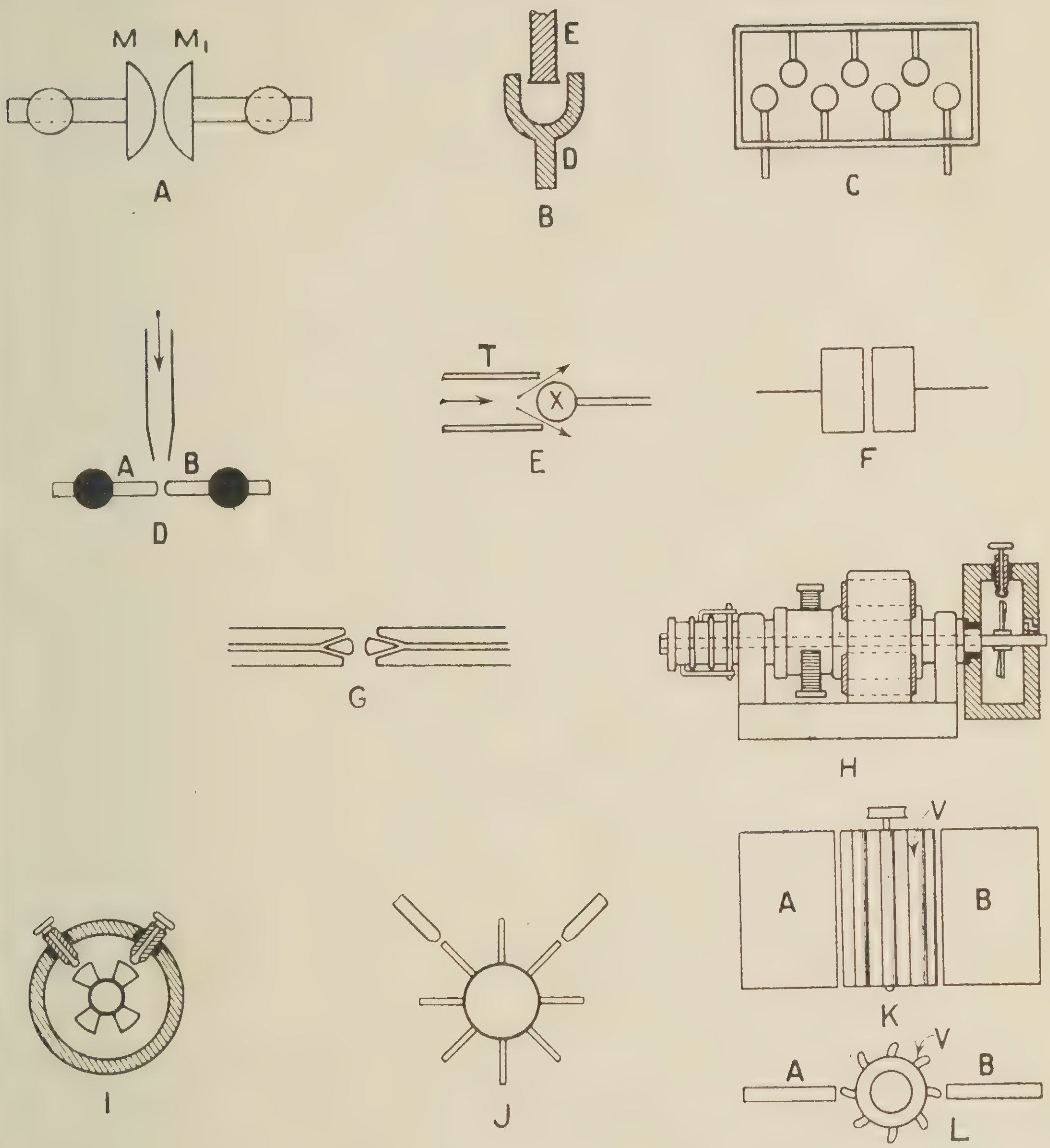


FIG. 81. Shows diagrammatically a number of forms of spark gap evolved by different investigators as described in text.

magnetic blast at right angles to the direction of the spark, this arrangement being known as a "Magnetic Blow-out."

Many experiments were made by various workers to improve the shape of the spark electrodes (85) and (4D).

Marconi Company's Mushroom-shaped Electrodes.—The Marconi Company employed large mushroom-shaped electrodes M and M_1, made of iron, in place of small knobs (A, Fig. 81).

Parallel Straightedge Gap.—Another form of spark gap is shown at F in Fig. 81, the spark taking place between two straight edges of metal, placed in a horizontal position.

Another way of using this gap was to place the opposing blades in a vertical position, a little wider apart at the top than at the bottom, and the air currents due to the heating effects of the sparks then caused the sparks, which started at the bottom of the plates, to run up them so that their edges were equally worn.

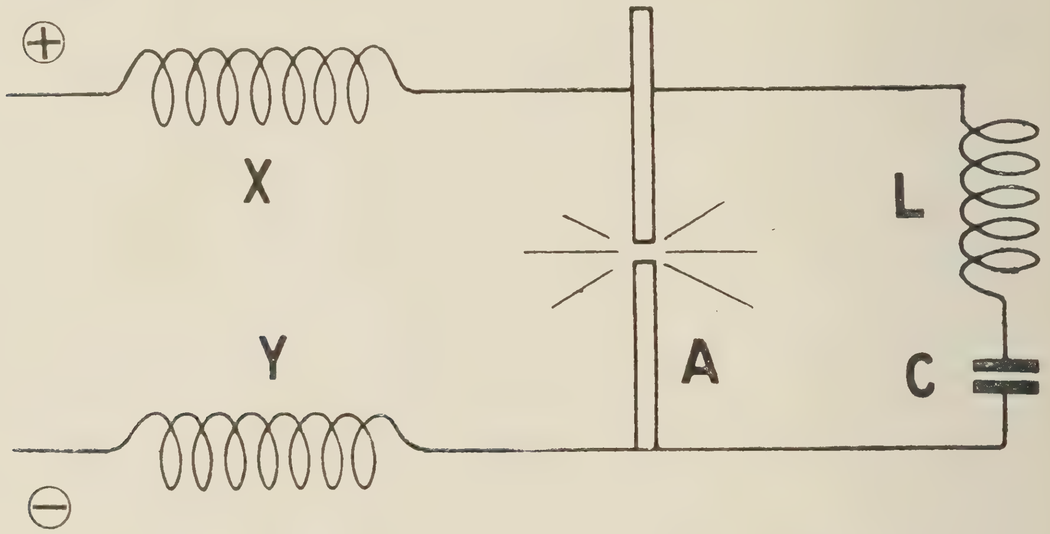


Fig. 82A. Illustrates the essentials of Duddell's Musical Arc, whereby electrical oscillations are produced in the circuit ALC.

Dubilier's Straightedge Quenched Spark Gap.—**Dubilier,** later, by arranging a number of such gaps in parallel, produced quite an efficient quenched spark gap for moderate powers (108).

M. Child's Spark Gap.—**M. Child** designed a spark gap (B, Fig. 81) in which the spark took place between a vertical electrode E and a cup-shaped electrode D. The concussion of the spark causes compressional waves in the cup, which tend to quench the spark.

Fleming's Spark Discharger.—In 1903 **Fleming** patented a spark discharger, consisting of a number of balls between which the spark takes place. These balls were caused to rotate slowly by a motor, and were enclosed in a chamber of compressed nitrogen or carbonic acid gas. He also arranged a

system of water-cooling for the balls, which were hollow (4D).

J. S. STONE'S MULTIPLE BALL EXCITER.—**J. S. Stone** (93) employed a multiple ball exciter similar to Righi's oscillator (C, Fig. 81).

W. DUDDELL'S MUSICAL ARC.—In 1900 **W. Duddell** (237), (238), (239), (56), carrying further the investigations of **Lecher** and **Peuckert** (240), (241), (50), showed the phenomenon of the musical arc, *i.e.* he showed that if a condenser and inductance were connected in series, and were shunted across an

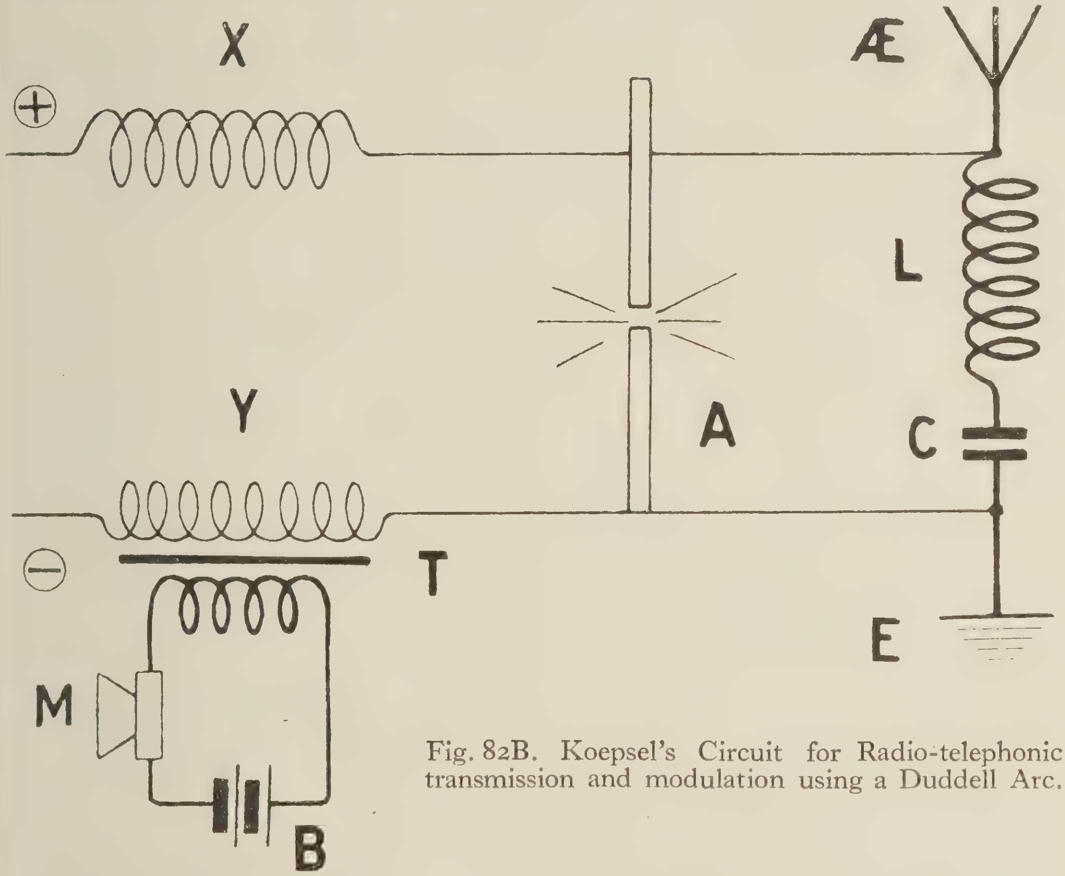


Fig. 82B. Koepsel's Circuit for Radio-telephonic transmission and modulation using a Duddell Arc.

arc, electrical oscillations were produced in this shunt circuit. These, in surging to and fro across the arc, would produce audible musical notes. The arrangement is shown in Fig. 82A. X and Y are two chokes, to prevent the oscillation from travelling along the supply leads. A is a D.C. arc, and L and C are the inductance and condenser respectively shunted across it. Duddell realized that the production of these pure sinusoidal electric waves would, if means could be found to increase their frequency, solve the problem of Wireless Telephony. As we shall see later, the problem was solved by **V. Poulsen** in 1902.

KOEPSEL'S ARC TELEPHONY EXPERIMENTS.—In 1903 **Koepsel** (50) devised a method of wireless telephonic transmission. He produced oscillations by means of a Duddell arc A, and coupled it to an aerial and earth E, as shown in Fig. 82B. This was not found to be very practical in use, as the oscillations were too feeble and at too low a frequency. The aerial had either to be excessively long or coiled. The oscillations were controlled by the voice by means of a microphone M and current from a battery B through a winding T inductively coupled to choke Y, which then became the secondary of a transformer.

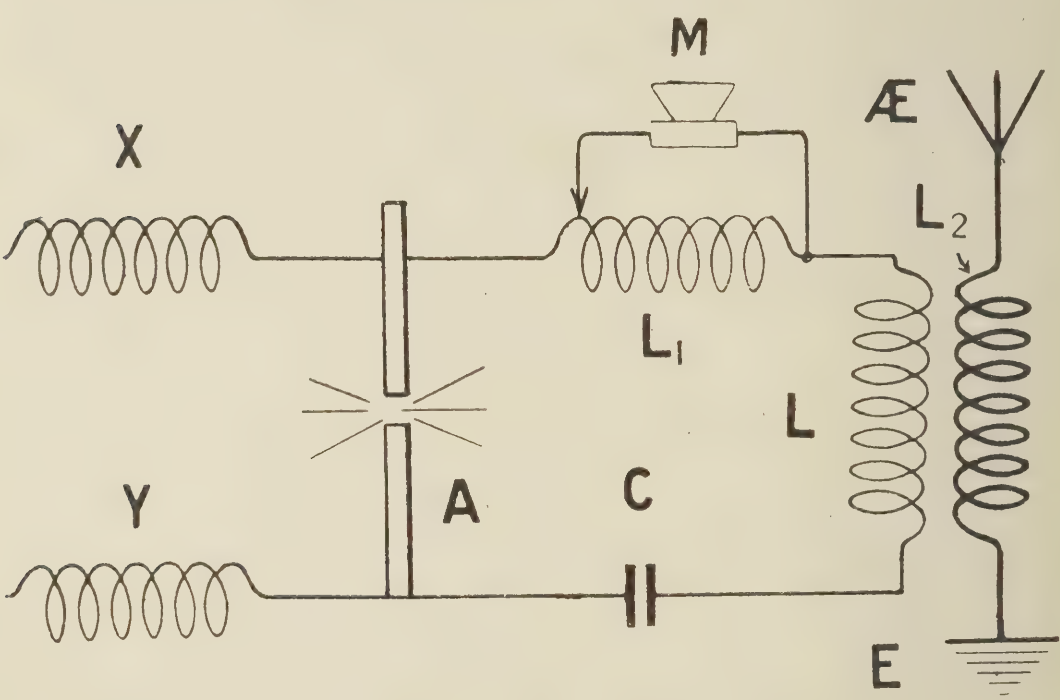


FIG. 82C. In this circuit, devised by Campos, the microphone is connected across part of the primary inductance.

CAMPOS' ARC MODULATION METHOD.—**Campos** (50) devised a very similar telephone transmitter to that of Koepsel; but, instead of placing the microphone in the primary circuit of a transformer, he placed it in parallel with an inductance in the oscillatory circuit, which he coupled inductively to the aerial (see Fig. 82C). X, Y are chokes, M is the microphone (no battery is employed), L and L_1 form the primary inductance, and C the capacity of the arc circuit. L_2E represents the aerial circuit.

EISENSTEIN'S METHOD.—In 1904 **Eisenstein** (50), (242), (243) took out British and German patents. His scheme was to make an inactive arc active when indirectly influenced by

sound vibrations, through a suitable transformer. The oscillations produced by the transformer reached a sufficiently high voltage to supply an aerial in which there was a spark gap.

Q. Majorana's Method.—In 1904 **Q. Majorana** (252) carried out a series of experiments at the Physical Institute of the University of Rome (50). He obtained a spark rate of 10,000 discharges per second. For this he employed an alternating supply current of 40 cycles, which he passed through the primary of a transformer, large choking inductances being arranged in the supply leads. The secondary winding of the transformer was connected to a very short spark gap, across which was arranged a blast of carbonic acid gas.

The oscillatory circuit connected to the gap was one having small inductance and capacity. With this arrangement he was able to transmit intelligible speech (50). For modulation purposes he employed a high-tension microphone (258) of his own design (Chapter XIII., see Fig. 113B) placed directly between the aerial and the spark gap. The principle of his microphone is as follows : A stream of acidulated water flowing at a regulated speed falls upon a flat metallic surface, over which it spreads. This metallic surface is placed in close proximity to another sheet of metal, and the liquid spreads over both, thus bridging the narrow gap between them. The stream of liquid, on its way to the jet, passes through a hollow chamber, one wall of which is covered with a thin membrane. When one speaks in front of this membrane pressure variations occur. causing the liquid to flow more or less quickly (the principle is similar to that of **König's** manometric flame (54)). The film of liquid connecting the two metallic plates is, therefore, varied in thickness, hence in its conductivity.

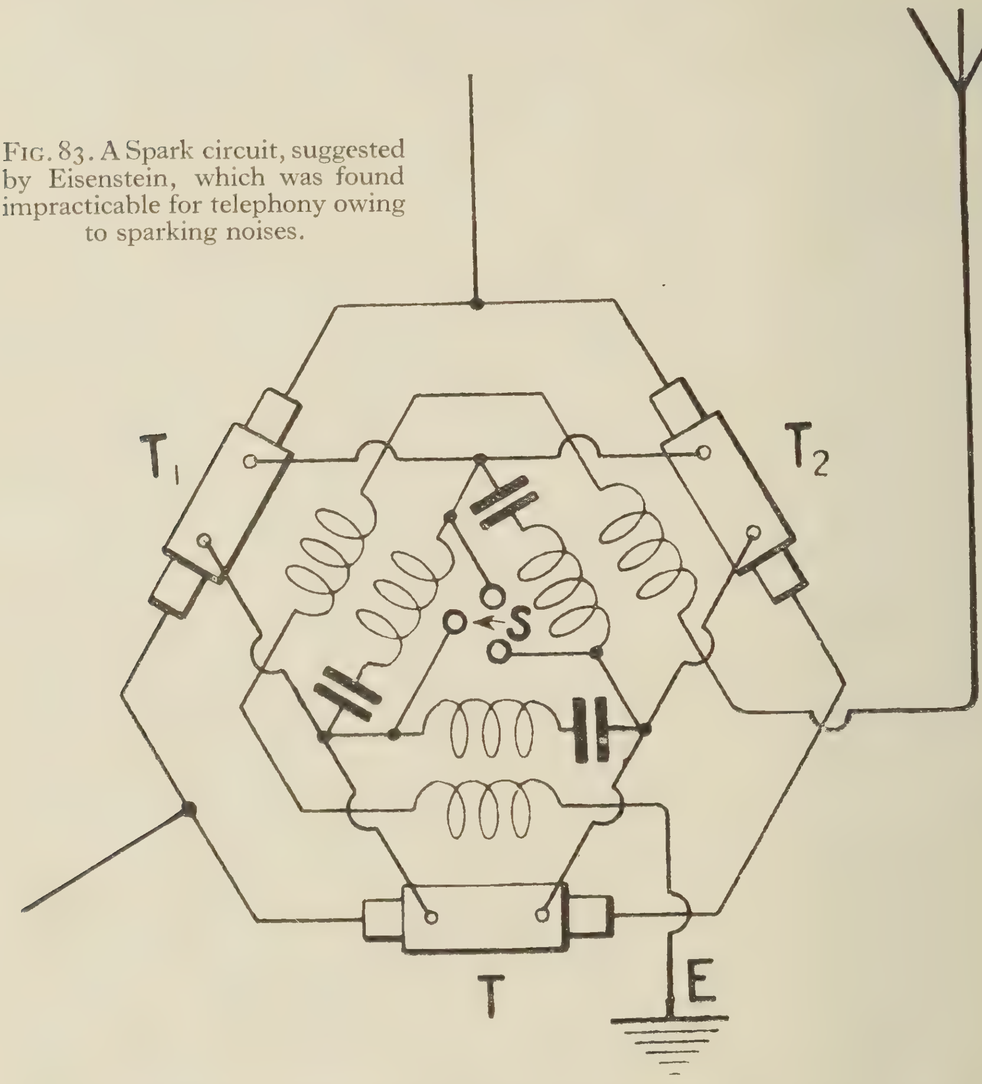
Acceleration of Sparking Rates.—It has been shown that when certain metals, such as zinc and aluminium, are employed as spark gap electrodes, there is a greatly reduced liability to arcing ; consequently, the spark gap can be reduced for a given voltage to an extent impossible with brass or metals, which " arc " more readily. This reduction in spark length, of course, increases the spark rate.

R. A. Fessenden and Others.—Between 1900 and 1904 (see Ref. 50), **R. A. Fessenden** succeeded in obtaining 20,000

sparks per second, using a 5,000-volt D.C. supply and a rotary spark gap running at 500 revolutions per second.

Speech was transmitted, but was to a great extent spoiled by sparking noises. **Eisenstein, Rühmer, Nussbaumer, Mosler, Simon, Reich,** and others (50) have devised most ingenious schemes for obtaining multi-phase currents, so as to obviate the time intervals between the spark discharges and so obtain a practically continuous discharge.

FIG. 83. A Spark circuit, suggested by Eisenstein, which was found impracticable for telephony owing to sparking noises.



S. EISENSTEIN'S METHOD.—Fig. 83 (which is taken from Dr. Erskine Murray's book by kind permission (50)) shows one three-phase method suggested by **Eisenstein** and patented in America in 1905 (340). Three transformers (T, T_1, and T_2) are coupled up to three oscillatory circuits, all exactly attuned. These, in their turn, are coupled inductively to the transmitting aerial system Æ, E. The sparks take place at S, between the three sparking balls.

Although no long pauses occur between the sparks when this arrangement is employed, it has not been found suitable for practicable telephony, owing to unavoidable irregularities and noises due to the sparking.

M. Wien's Quenched Spark Investigations.—In 1906 **Max Wien** (92), (85) discovered, in the course of some researches on electrical discharges between metal electrodes in close proximity, that the oscillations in a closed circuit could be quenched rapidly by a suitable gap, so as to allow an open circuit coupled thereto to vibrate freely in its own period. (For the theory of the quenched spark see references (199–111)). Following this discovery, many investigators brought forward methods whereby primary circuit sparks could be quenched.

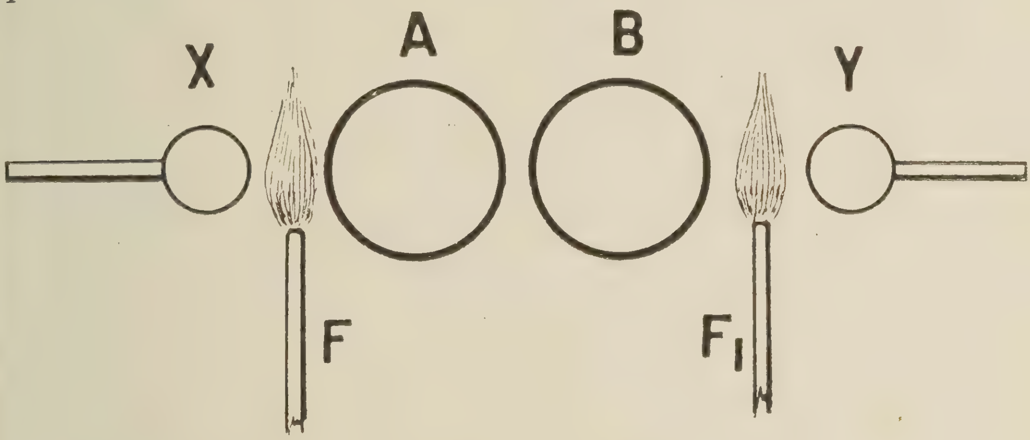


Fig. 84. A form of spark gap due to Koehler.

F. Lowenstein's Air-blast Spark Gap.*—**Lowenstein** (85) employed a blast of air across the spark gap between two electrodes A and B, Fig. 81D.

Massie's Air-quenched Spark Gap.—Another air-quenched spark gap due to **Massie** (85) is shown in Fig. 81G. In 1909 (4d), (96) **Fleming** and **Richardson** devised a spark gap (Fig. 81E) in which the spark took place between the edges of a hollow metal tube T and a metal ball X. The spark was quenched by an air blast taking place down the length of the tube.

I. Koehler's Spark Gap.—Fig. 84 illustrates this device. The supply current to the main gap between two metal knobs A and B is fed from two smaller knobs X and Y through two gas flames F and F_1.

* In 1914 **Lowenstein** patented a multiple spark gap (823) in which air was drawn through between the sparking surfaces by means of an electric fan.

A. Shaw's Air-blast Spark Gap.—In 1912 **A. Shaw** (92) patented another form of air-blast spark gap. The spark took place between the end of a hollow cone and the centre of a flat metal plate, and a blast of air having a pressure of about 100 lbs. per square inch passed through the centre of the cone and quenched the spark so effectively that, under correct conditions, the discharge consisted of a series of unidirectional impulses of extreme rapidity (92).

The patent also covers the employment of a series of these air blasts arranged on a revolving disc, which causes them to revolve in front of fixed electrodes, and so produces a musical note.*

Nikola Tesla's Rotary Gap, and His 1896 Patent.—In 1896 **Nikola Tesla** took out a British patent (1027) of great importance, covering many points in the production of high-frequency electric currents.

He says (on page 2 of the patent specification): "When the apparatus is to be employed for the purpose of converting a direct current of comparatively low potential into one of high frequency, a device in the nature of a choking coil is interposed in the circuit in order that advantage may be taken of the discharge of high electro-motive force, which is manifested at each break of such circuit, for charging a condenser."

The drawings attached to his specification show iron core chokes, and no mention is made of the chokes functioning to prevent oscillations from being dissipated back through the mains and the dynamos.†

His patent also covers the employment of a rotary spark gap, both synchronous on the shaft of the alternator and non-synchronous. The rotor of the spark gap takes the form of an electric fan. Figs. 81 H and I are reproductions from the patent specification drawings of his rotary spark gap, driven on the end of the alternator shaft.

Marconi's Synchronous Gap.‡—Marconi also employed a synchronous gap driven on the shaft of the alternator. It is very similar to that of Tesla, but the fan blades are replaced by short metallic spokes (Fig. 81J).

Balsillie's Rotary Gap.—In December 1909 the British Radio Telegraph and Telephone Company exhibited at the

* **Nikola Tesla** had already described the use of a rotary gap. See his British patent of 1896 (1027). See also **Balsillie's** rotary gap of 1909 (106), (891).

† In 1892 **Elihu Thomson** (124) patented circuits in which direct current was led from supply mains through a large choking coil to a spark gap shunted by an inductance and a condenser in series, a magnetic blast being arranged across the spark gap.

‡ Reference should also be made to **Marconi's** disc dischargers at end of Chapter XII

Physical Society's Exhibition a rotary spark gap designed by **J. G. Balsillie** (106), (891).

The scheme of this gap is indicated in Fig. 81, at K and L. The oscillating circuit is connected to two metal plates A and B, $4\frac{1}{2}$ins. long, and sparking takes place between these

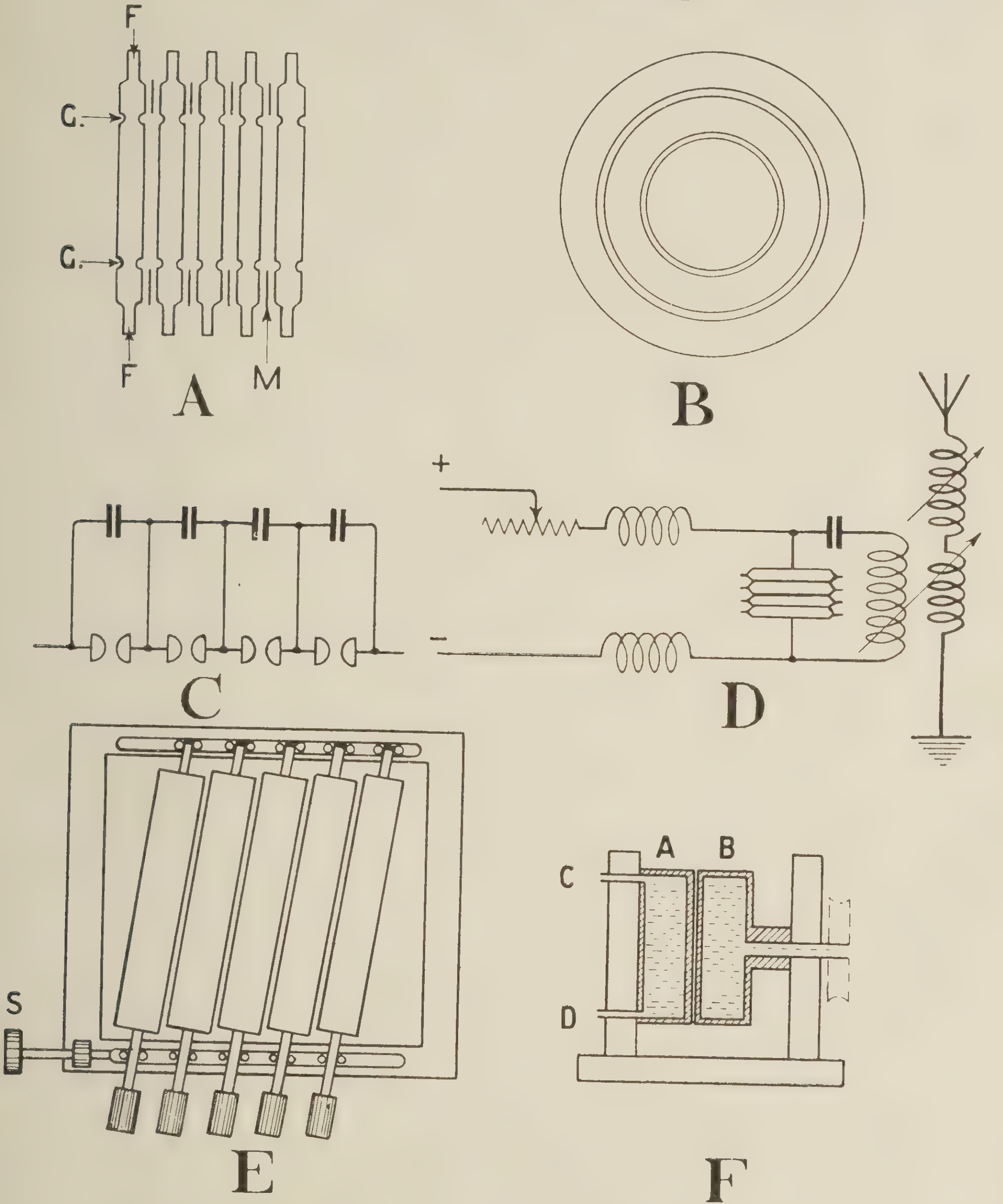


Fig. 85. A and B illustrate the Telefunken Quenched Spark Gap, and D shows a suitable circuit for use with a D.C. supply. An earlier Telefunken Multiple Gap is shown at C.

Fig. 85E. A revolving gap employed by La Compagnie Générale de Radio-télégraphie

Fig. 85F. A rotary quenched spark gap due to Coursey. (See page 174)

two plates and long curved vanes which revolve between them ; these have straight edges, but are curved so as to act also as fans.

(Litigation took place between Marconi and others and the British Radio Telegraph and Telephone Company in 1910 with regard to priority of patent rights.)

FESSENDEN'S ROTARY GAP AND SPARK IN COMPRESSED AIR. —Fessenden also employed a rotary gap. He also carried out a series of experiments with sparking taking place in compressed air, and he found that no increase of radiation takes place below a pressure of 3·3 atmospheres; but at 5·3 atmospheres the carrying power of the waves was, he claimed, $3\frac{1}{2}$ times greater than with a plain air gap.

MARCONI'S HIGH-SPEED ROTATING DISC DISCHARGER.— Marconi's High-speed Rotating Disc Discharger is described later in this book. (Pages 190-193).

THE DUCRETET ROTARY SPARK.—Many other workers invented devices for interrupting sparks. A rather ingenious device of this character was known as the "**Ducretet**" Rotary Spark (107), and was invented in Paris between 1910 and 1911. In this the spark takes place between the open end of an aluminium tube, through which a draught of air is being forced, and a copper ball, which is also being revolved on an axis at right angles to the tube just in front of its opening.

W. DUBILIER'S ROTARY SPARK.—**W. Dubilier** patented a rotary spark gap in 1910 (108), (118), (123), described later in this chapter. (Pages 172-174).

THE TELEFUNKEN QUENCHED SPARK.—Another very important method of spark quenching is employed by the Telefunken Company (92), (108), (114-117), (122), patented in Germany in 1908 and in England the next year.

Fig. 85 A and B illustrate the Telefunken Quenched Spark Gap. The gap consists of a series of flat silver-plated copper discs; the outside of each disc is turned down to form a cooling flange F, and a groove G is cut right round the flat surface of each disc on each side. These discs are placed against one another, and separated by mica rings, which project half-way across the groove G. Two discs (that is to say, one spark gap) are required for about every 600 volts when mica rings 0·1mm. in thickness are employed (108).

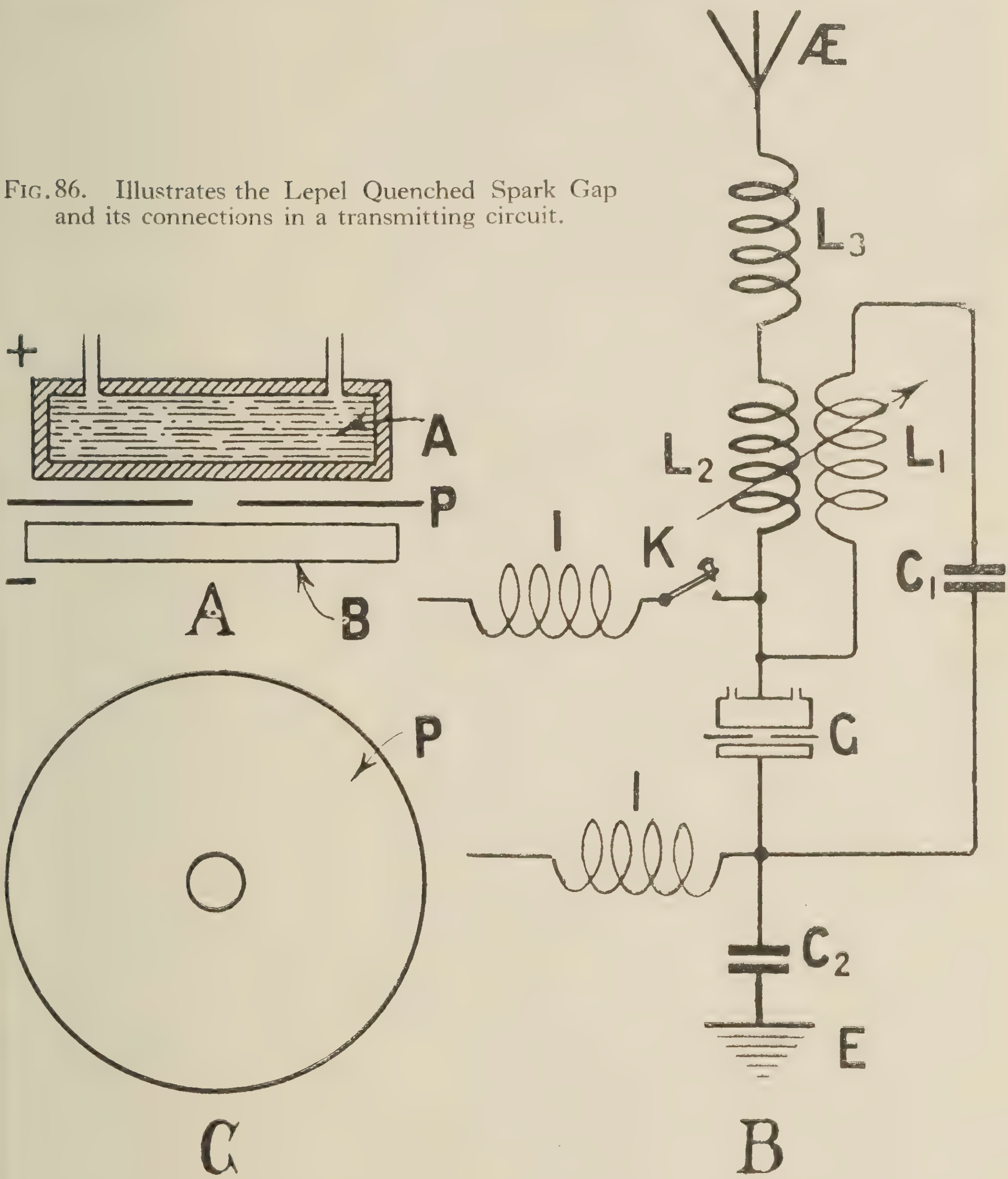
The Telefunken spark gap is employed in the primary oscillatory circuit of a wireless transmitting station, and can be supplied with current from an induction coil, an alternator, or with direct current. Fig. 85D shows the connections used for working from a D.C. supply (108)*. Fig. 85C illustrates

* See also W. P. Thompson's spark gap—Ref. No. (836).

another and obsolete multiple gap employed by the Telefunken Company (85).

Egbert von Lepel.—**The Lepel Quenched Spark Gap** (292), (121), (108), (92), (291). **Baron von Lepel,** of Berlin, was the inventor of the Lepel Gap (873) and (874), which is fed with

Fig. 86. Illustrates the Lepel Quenched Spark Gap and its connections in a transmitting circuit.



a supply voltage of from 400 to 500 volts, either D.C. or A.C. It is shown in diagrammatic form in Fig. 86A. The gap consists of a water-cooled copper electrode A about 3ins. in diameter, which rests on a plate of Delta metal (a hard brass, containing a small percentage of iron). The flat surfaces of these electrodes are separated by one or two thicknesses of

thin paper, except at the centre, where a small hole is cut, leaving an exposed space between the plates. The paper very slowly burns away (one piece lasting during several hours' continuous working). Owing to the heating of the current bridging the gap, the paper becomes charred and produces various gases, which assist the quenching.

The connections of the gap are shown in Fig. 86B. The primary circuit consists of an inductance L_1 and a condenser C_1, the former as small as possible and the latter large. The aerial circuit (Æ, L_3, L_2, G, C_2, E) includes the spark gap, coil L_2 of the former being coupled to coil L_1 of the primary circuit (both open and closed circuits being tuned to the same frequency). When this gap is worked from a D.C. supply, the discharges follow each other at a frequency above the limits of audition, and cause a hissing noise in the receivers ; but when alternating current is employed a musical note is received.

The note from D.C. can be made musical by connecting an additional oscillatory circuit, comprising capacity and inductance of suitable value for oscillating at the desired audible frequency, as shown by Duddell in 1900 (50). Lepel arranged a keyboard, which varied the frequency at will, and by its means he transmitted tunes.

In the early days of Wireless many experimenters will remember hearing "God Save the King" and other tunes transmitted from the Lepel stations at Slough and Twickenham, and also the hissing notes of the D.C. gap, when used alone.

PEUKERT'S DISCHARGER.—In 1909 **W. Peukert** (296), (4d), (92), (97), (112) took out English patents for a discharger which worked on a comparatively low D.C. current when placed in series with an inductance and condenser. This consisted of two discs in a horizontal position, one stationary and the other rotating at a high speed in very close proximity to it, the space between them being fed with oil.

FLEMING AND DYKE DISCHARGER.—**J. A. Fleming** and **G. B. Dyke** (108) have improved on this gap. They also employ rotating discs and an oil dielectric.

The discs are made of case-hardened steel ; the upper one is mounted on a spindle and runs on ball bearings at about 2,000 revolutions per minute ; the lower disc is stationary,

and has a hole in its centre through which oil is sucked to replace that which is thrown outwards from between the discs by centrifugal force. This gap has worked very satisfactorily over long periods.

Lodge and Chambers' Rotary Disc Discharger.—**Lodge** and **Chambers** (4d) have also invented a rotary disc discharger.

Wien's Quenching Tubes.—In 1910 **M. Wien** (244) invented a new kind of impact excitation of electric oscillations. As an alternative to the quenched spark gap he connected Geissler tubes in series with an ordinary spark gap. Their resistance rapidly damped out the oscillations, thus supplying the required quenching action. The tubes are termed " quenching tubes " ; they are fitted with silver electrodes, and are first filled with hydrogen and then exhausted to about 1·0mm. of mercury.

Chaffee's Quenched Spark.—In 1911 **E. L. Chaffee** (126), (108), (227), (228) discovered that if a quenched spark gap were formed between electrodes of aluminium and copper, relatively small surface areas were necessary when compared with those required with the " Telefunken " and similar gaps. From researches made by **Washington** and others, it appears that the successful operation of the gap depends upon the formation of a film of oxide on the surface of the aluminium.

The " Chaffee High-frequency Spark System," as it is called, can be used as a small-power Radio-telephony Transmitter up to ranges of about 100 miles.

Fig. 87A is a diagram of the " Chaffee " spark gap, as slightly modified by **B. Washington** (228) and (227) (for the original " Chaffee " gap see reference (108)). The electrodes E and E_1 are about 0·3 square inch in area, and the length of the spark gap is between 0·04 and 0·09mm. One electrode E is fitted in an insulated back plate, and has cooling flanges F as shown.

The other electrode E_1, which is also fitted with cooling flanges F_1, is attached to the centre of a phosphor-bronze diaphragm D, and the exact length of the spark gap is adjusted by slightly bending the diaphragm in or out by means of a set-screw, as shown. (The aluminium electrode must be connected to the negative supply lead.) The chamber C, enclosed by the solid back and the diaphragm, in which the spark takes place, can be filled with hydrogen gas or alcohol vapour. When more power is to be dealt with, the gap con-

sists of an aluminium disc rotating rapidly in front of a stationary copper plate (227).

Fig. 87B, (Ref. 227), shows the connections employed by Chaffee for Radio-telephony. The spark-frequency is arranged so as to be exactly one-half, one-third, or one-quarter of the oscillation frequency. This ensures that the spark will always strike up in phase with the oscillations, and prevent a hissing sound in the receiver, which may be set up by the beat action of a spark not perfectly tuned. The sparking frequency depends on the capacity of the closed oscillatory circuit and on

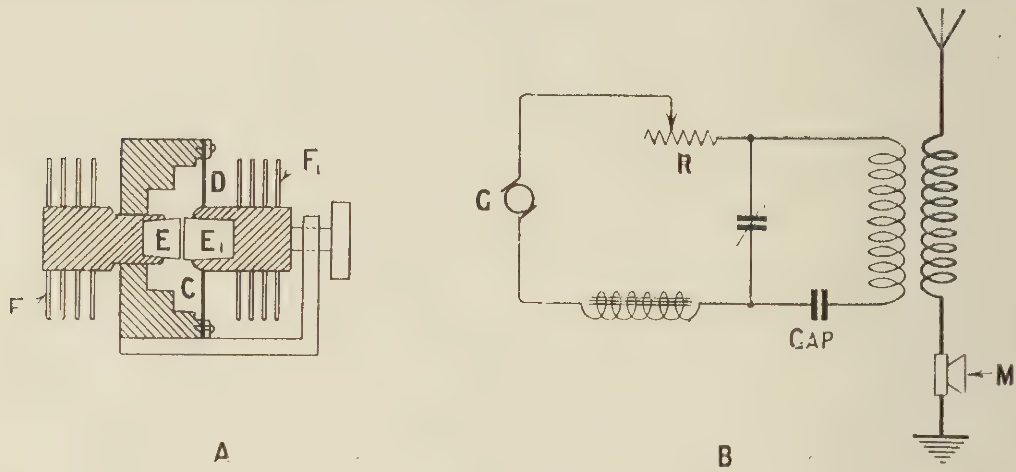


FIG. 87A. Shows Washington's modification of the Chaffee Spark Gap.
FIG. 87B. Chaffee's Circuit for telephony transmission.

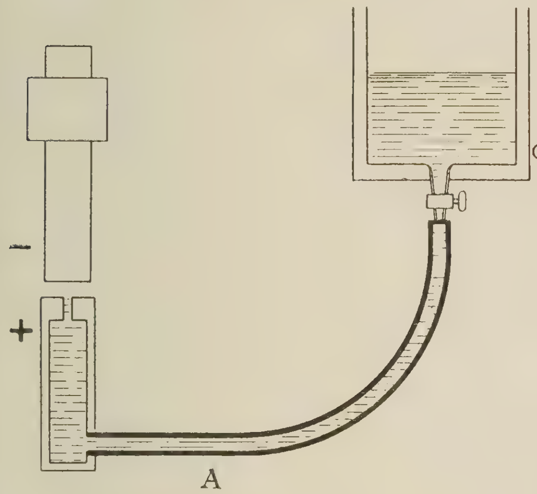
the strength of the supply current. On 500 volts supply, two gaps are employed in series, or four gaps in series for 1,000 volts. A single gap will work at as low a voltage as 150 volts. The critical adjustment of the spark frequency depends on the supply current, and it is, therefore, obtained by varying the resistance R. The microphone M is of the ordinary low resistance type.

DITCHAM'S SPARK GAP.—**Ditcham** (108), (229), (92) employed a spark gap in 1913 very much like that of Peukert in design, using discs of aluminium (cathode) and copper (anode), so arranged that one is stationary and the other rotates ; but he replaced Peukert's oil film with hydrogen gas in the space between the plates. With a gap of this design he was able to carry on quite successful telephony over small distances.

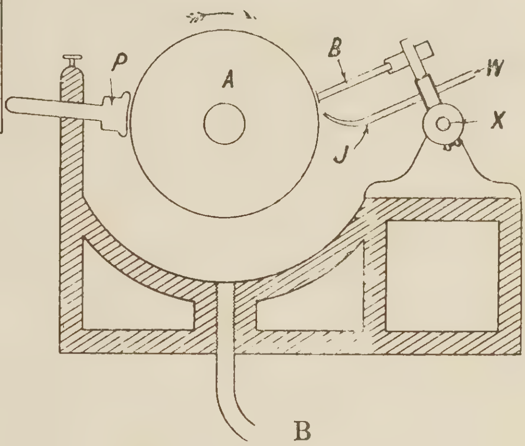
DE FOREST'S TUNGSTEN SPARK GAP.—**De Forest** also has a spark gap (227), which consists of two tungsten electrodes in close proximity, the gap being adjustable in length. One gap

suffices for a 600-volt direct current supply; but for 1000-volt D.C. two are employed in series.

THE T.Y.K. SPARK GAP—British patent 10823, 1912, (227), (108), (92), (786).—This system has been used with success for some time in Japanese ships, particularly for the transmission of Morse; it is due to **W. Torikata, E. Yokoyama,** and **M. Kitamura.** In their 1912 patent they state that they have discovered that many other substances in addition to aluminium, when used as arc electrodes and shunted by a suitable capacity and inductance, will produce a spark frequency well above audible limits; and that, as in the case of



A



B

Fig. 88A. The Moretti "Deflagrator."

Fig. 88B. In Jackson's Arc the electrodes are a metal rod B and a rotating metal cylinder A, covered with a film of water.

aluminium, a semi-insulating film appears to be formed between the electrodes by the first discharge, which prevents the gap from becoming short-circuited, though not preventing the discharges (92). The electrodes they make use of are quite small in surface area; in fact, they may actually be pointed. The following are some of the substances employed: Aluminium, silicon, ferro-silicon, carborundum, bornite, magnetite, iron pyrites, copper pyrites, graphite, marcasite, etc.* According to Dr. Eccles (92), their most practical apparatus employs a 500-volt discharge between electrodes of magnetite and brass, shunted by a small inductance and a large capacity.

THE MORETTI GAP (or MORETTI "DEFLAGRATOR") (56), (62), (92), (227), (890).—This gap is supplied with a direct current of 600 volts; the electrodes are of copper, and placed vertically. The arc is struck between the negative electrode

* At the 1921 Exhibition of the Physical Society, A. Hilger exhibited an arc sustained between two fragments of the titanium ore known as ilmenite. With these electrodes on 220 volts a 1-ampere arc will run for three or more hours.

(which is uppermost, and consists of a solid copper rod) and water, which is pumped at a regulated speed steadily up through a copper tube, the positive electrode being actually the water itself. A diagram of this arc is shown in Fig. 88A.

Using a Moretti "Deflagrator" in conjunction with his own liquid microphone (see Chapter XIII., Fig. 111C, of this book), in 1912 **G. Vanni** transmitted speech from Centocelle (near Rome) to Tripoli, a distance of about 625 miles.

This gap has also been elaborated (227) by giving a rapid movement to one electrode.

W. J. Jackson's C.W. Generator (886).—This apparatus, shown in Fig. 88B, was patented by **Jackson** in 1914. One electrode consists of a rotating metal cylinder A, covered with a film of water supplied by a jet J; and the other electrode B, which takes the form of a rod, is mounted to slide along a bar X. P is a felt pad which removes superfluous water.

Jackson has also invented a modification of the above, in which he employs a fixed rod and a rotating disc the lower part of which dips into a water-trough.

H. P. Dwyer's Arc (282), (108).—This arc is very similar to that of Moretti, except that the arc is struck under the surface of alcohol, and that alcohol, instead of water, is pumped through the copper anode. The cathode is usually made of aluminium, and is hollow and water-cooled.

Eccles' and Makower's Investigations of Sparks in Liquids (92), (113).—**Eccles** and **Makower** carried out a series of experiments with sparks in running liquids, and they found that to obtain maximum sparking efficiency the correct rate of flow of the liquid across the gap had to be employed, *i.e.* when using water, if the flow were too slow, arcing took place, and if the flow were too rapid no spark passed at all, but much energy was wasted owing to the conductivity of the water. Using transformer oil in place of water, the results were approximately equal to those obtained by the use of an air gap, with the advantage of the silencing of the spark noises; also, when oil was employed they found that single impulse excitation was taking place, so that much sharper tuning was obtainable and only one wavelength was radiated, even when primary and secondary circuits were closely coupled (whereas, with an ordinary air gap, with close coupling, two distinct waves are radiated simultaneously).

W. Dubilier's Rotating Spark Gap.—The following is a description of **W. Dubilier's** Rotating Spark Gap referred to

before, and also his vibrating arc, as described in "The Electrician" of December 12th, 1913 (123), (124), (887), (889).

The electrodes are shaped as shown at B in Fig. 89.

The fixed electrode E_1 is given a concave surface, and the spokes are coned, so that, as they revolve, there is always an equal active surface area. The arc between these two electrodes first gives undamped oscillations, as shown at X, Fig. 89A; but when electrode E_2 (Fig. 89B) arrives at the bottom of E_1 (at point E_3) the arc is suddenly broken, and, owing to the voltage from the generator A (Fig. 89C) and the inductance coils B and B_1, the condenser C suddenly charges

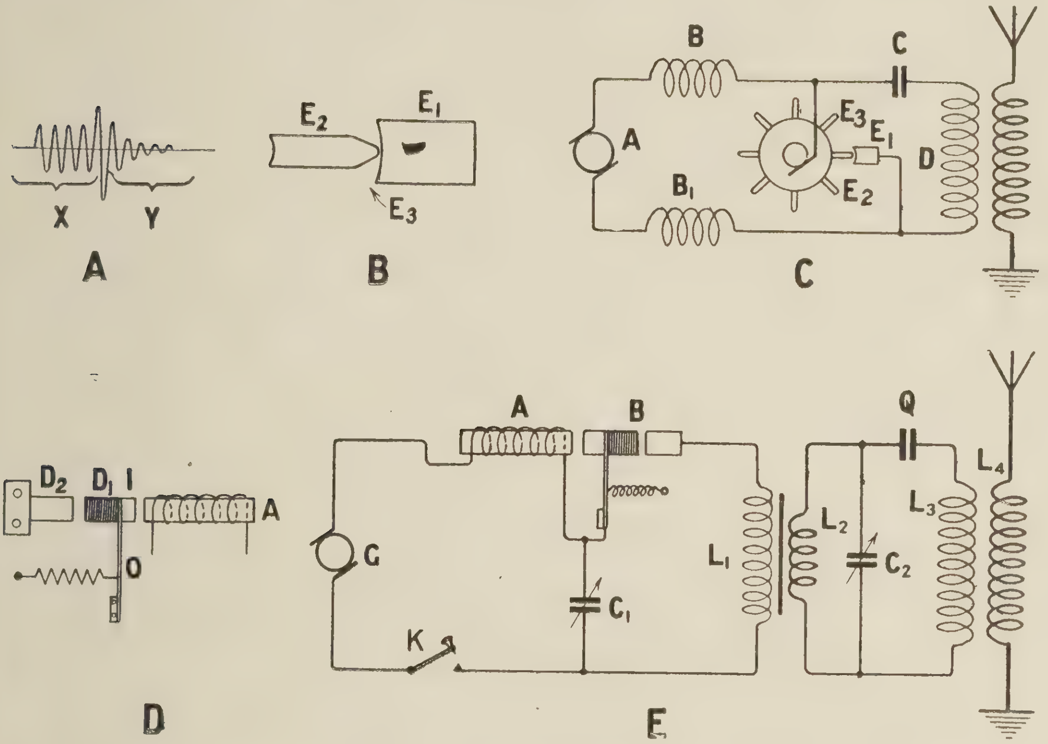


FIG. 89. C is the circuit for use with Dubilier's Rotating Spark Gap. A and B illustrate points referred to in the text. D and E show another form of Dubilier's Spark Gap and the circuit in which it may be used.

to a much higher potential. After the arc is broken, the oscillatory circuit E_2, C, D is open, so that radiation takes place, as with a quenched spark. Tuning is practically as sharp as when undamped oscillations alone are employed. The end of the electrode E_1 is made with a curvature concentric with the axis of the rotor E_2 (Fig. 89B), so that when the electrode E_3 passes across its surface it is equidistant from it for a determined distance, during which time the practically undamped oscillations of equal amplitude are produced. Directly the arc is broken by the passing of electrode E_2

away from electrode E_1 the amplitude of the oscillations is rapidly increased, and they are then damped as indicated at Y (Fig. 89A). By suitable choice of voltage, and other factors, a musical note is produced. For instance: "By giving the rotary device a speed of 1,500 revolutions per minute, or 25 revolutions per second, 30 spokes or electrodes being used, 750 trains of waves per second are obtained."

For small equipment (and for electro-medical purposes) dealing with about 150 watts, Dubilier employs a vibrating electrode spark gap (or oscillator). This is illustrated in Fig. 89D. A low voltage arc (from 200 volts supply) takes place between platinum or silver electrodes D_1 and D_2, 25mm. in diameter. The former is carried by a very stiff spring O and is backed with a small block of iron I, and the latter is a fixed electrode. The arc is connected in series with an electro-magnet A, which vibrates the electrode D_1 and at the same time functions as a choke coil.

Fig. 89E is a diagram, also from "The Electrician" of December 12th, 1913, showing the Dubilier transmitting connections (see also British patent No. 16917, 1913). G represents a small 200-volt D.C. generator. The oscillating circuit consists of the oscillator B the vibrating reed of which is tuned to a frequency of 500, condenser C_1, and the primary L_1 of a step-up transformer. This circuit is also tuned to a frequency of 500. (Owing to the mechanical and electrical frequencies being the same, no sparking takes place between the electrodes, which are in contact when not in action.)

The circuit L_2C_2 is also tuned to the same frequency, though its voltage is raised by the transformer to about 12,000 volts. A quenched spark gap Q, and an inductance, are connected across the condenser C_2, and this circuit is inductively coupled to the aerial.

PARALLEL CYLINDER QUENCHED SPARK GAP.—In France, La Compagnie Générale de Radio-télégraphie in 1913 employed a parallel cylinder quenched spark gap (108), (119). The sparks take place between a number of revolving cylinders, the distances between which can be adjusted by a set-screw S (Fig. 85E) page 165.

THIEME'S MODIFICATIONS.—**B. Thieme** suggested various modifications of this gap in 1914 (120).

Fessenden's Parallel Cylinder Gap.—**Fessenden** invented a very similar Parallel Cylinder Rotary Multiple Arc at about this date (50). (1913)

P. R. Coursey's Rotary Quenched Spark Gap.*—Fig. 85F shows **P. R. Coursey's** Rotary Quenched Spark Gap (108). The spark in this gap takes place between the flat surfaces of two water-cooled electrodes A and B, the former being fixed, and the water circulating through the tubes C and D. Electrode B is rotated by a motor, and is also water-cooled through a tube in the shaft (not shown in the figure).

* See also Ref. 163. Fessenden's Water-cooled Rotating Electrode Spark Gap.

CHAPTER XII.

The Multiple Arc, Hydrogen Arc, Mercury Vapour, and Some Other Methods of Producing High-frequency Oscillations

Arcs in Series in Air (Multiple Arc)

Since **Wm. Duddell,** in 1900 (238), employed a D.C. Arc as a Generator of Alternating Currents many workers have carried out investigations in order to increase the efficiency of this method, and in order to give it practical application by increasing the frequencies of the oscillations. In his 1900 patents Duddell showed that several arcs might be employed connected in series, burning in air between carbon electrodes. The "Gesellschaft für drahtlose Telegraphie," of Berlin, succeeded in 1906 (four years after Poul-

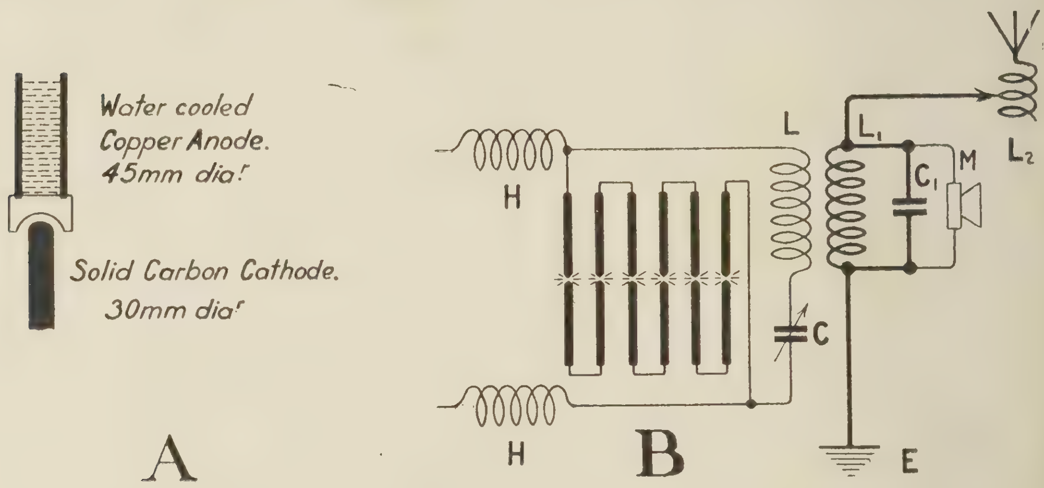


Fig. 90. Six arcs of the type shown at A, connected in series as at B, were employed successfully in 1906 for telephony between Nauen and Berlin.

sen's great discovery of the Hydrogen Arc) in obtaining a frequency of 500,000 from a 220-volt D.C. supply, with a current of 5 amps. To achieve this they employed six arcs in series. The six positive electrodes were hollow cylinders of copper, filled with water, and supported in vertical position. The bottoms were also made of copper, and concave in shape. The arcs were struck between these concave copper surfaces and solid arc carbons, and by means of a mechanical device the arcs could be fed and controlled individually or collectively.

Figs. 90A and 90B show the arrangement (50), (56). The method was put to successful test between Nauen and Berlin, in December of the same year (1906), the output being controlled by a microphone.

For reception an electrolytic cell was employed (259).

POULSEN'S ARC IN HYDROGEN.—In 1902 **Valdemar Poulsen** (260 to 271), (377), (50), (108), (4D), (394), (837), (1011) showed that by placing a Duddell arc in hydrogen, a hydrogen compound, or another gas of high thermal conductivity, instead of burning it in air, really powerful undamped electrical oscillations of high frequency could be produced. He obtained improved results by using a water-cooled metallic anode (usually copper) and a carbon cathode. He also placed a magnetic blast at right angles to the arc.*

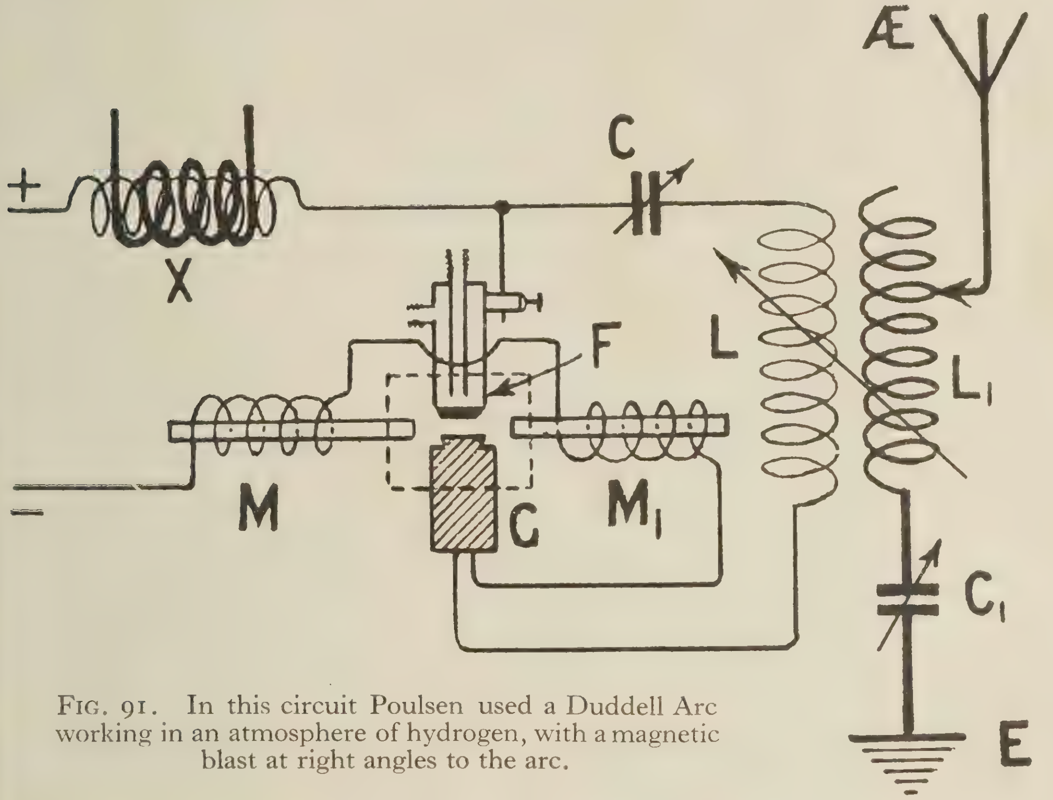


FIG. 91. In this circuit Poulsen used a Duddell Arc working in an atmosphere of hydrogen, with a magnetic blast at right angles to the arc.

Fig. 91 shows the connections employed by Poulsen, from which it will be seen that the windings of the magnetic poles M M_1 are arranged in series with the arc across the supply mains. F represents the water-cooled copper anode, G the carbon; X is an air choke in the positive main. For telephony, the arc is modulated by means of a battery and microphone, in series with a secondary winding round the choke, which then becomes a transformer. This illustration is reproduced from a paper on the D.C. Arc given by the **Author** to the Wireless Society of London in 1914 (56).

* It is interesting to note that Elihu Thomson suggested the use of a magnetic blast at right angles to the spark of his high-frequency generator in his 1892 American patent (272), (273).

Fig. 92 is a photograph of a small arc shown working at that lecture.

Fig. 93 is a diagram showing its construction and connections. Not only is the anode water cooled, but so also is the entire arc chamber. Instead of the magnetic blast at right

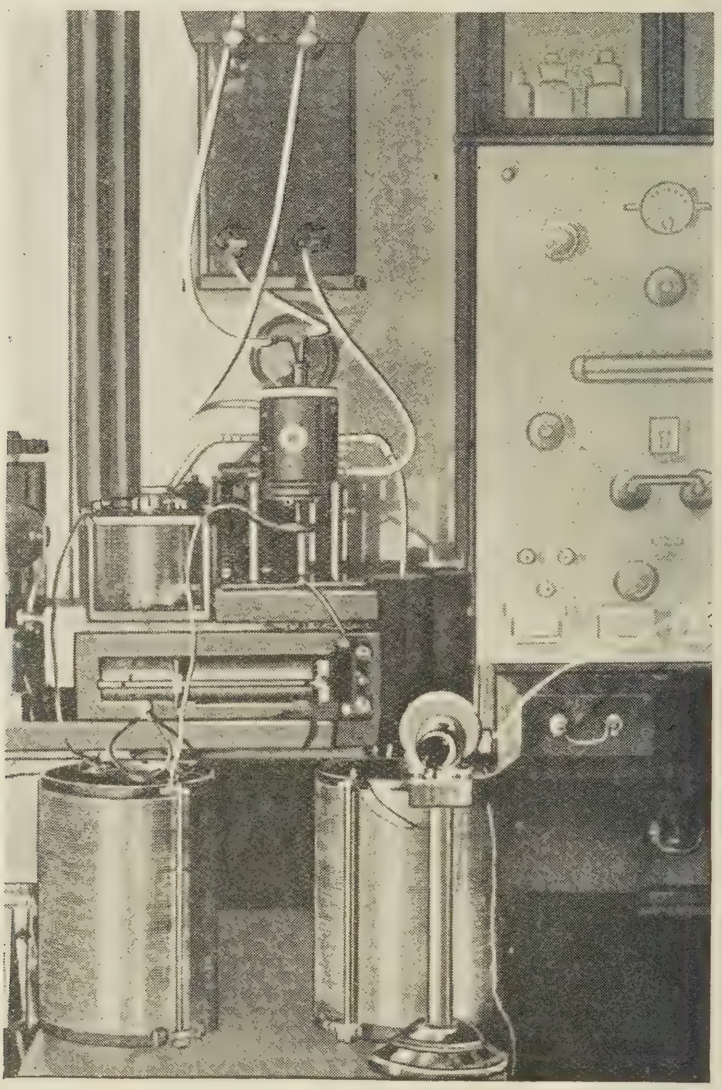


FIG. 92. The arc transmitter used by the Author in 1914.

angles to the arc, a magnetic field is placed below the carbon with the view of causing the arc to rotate, and so burn away the carbon more evenly. Successful transmissions were made with this arc between Richmond and the London Telegraph Training College at Earl's Court in 1913, on a 220-volt D.C. supply (an extremely low voltage for the purpose, but the only one then available). On this voltage the adjustment of the arc was found to be exceedingly critical.

Fig. 94 shows a photograph of a 25 kw. arc kindly lent for reproduction by the courtesy of the Marconi Company. In their patent of 1913 (295) **Pedersen** and **Poulsen** show special methods of connecting two or more tuned arc circuits to an aerial instead of running the arcs in series, it having been shown that a simple parallel arrangement is useless because the arcs will not run in phase (92).

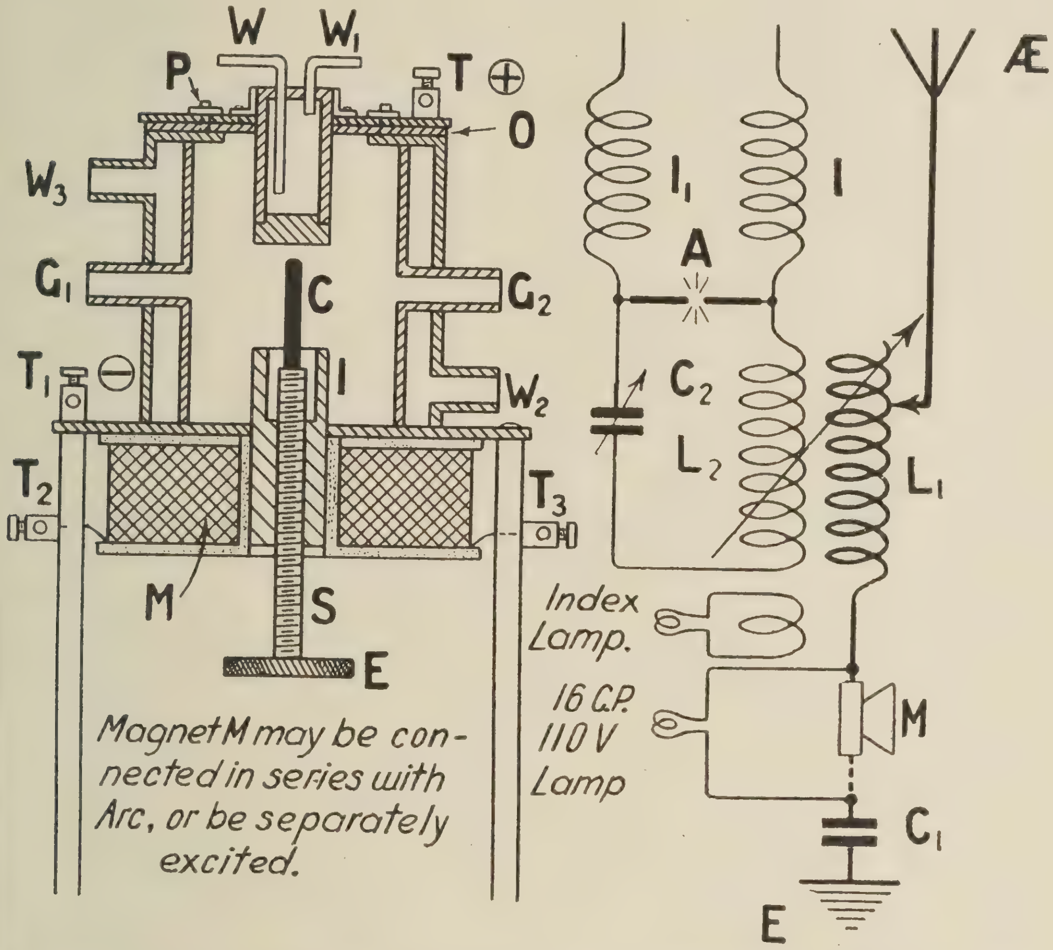


FIG. 93. Details of the construction of the arc and the circuit employed by the Author in the transmitter illustrated on the previous page.

O. SCHELLER'S VAPORIZED SPIRIT ARC.—In 1901 (871) **O. Scheller** patented a method of feeding an arc chamber with hydrogen by allowing a liquid hydrogen compound (such as methylated spirit) to drip from a reservoir on to one or both of the hot electrodes, where it is vaporised. This method is in very general use. Such a reservoir is seen above the arc in Fig. 94. (Kindly lent for reproduction by the Marconi Co.).

POULSEN'S GAS FLAME ARC.—In 1905 **Poulsen** (850) patented a method in which an arc was arranged to take place in a

gas flame. The arc was shunted by the usual oscillatory circuits containing a condenser and inductance. Signalling was achieved by squeezing the gas supply pipe with an operating key; or automatic transmission could be effected by moving a perforated strip across the opening through which the gas was passing. Powders or liquids could be used in place of gas.

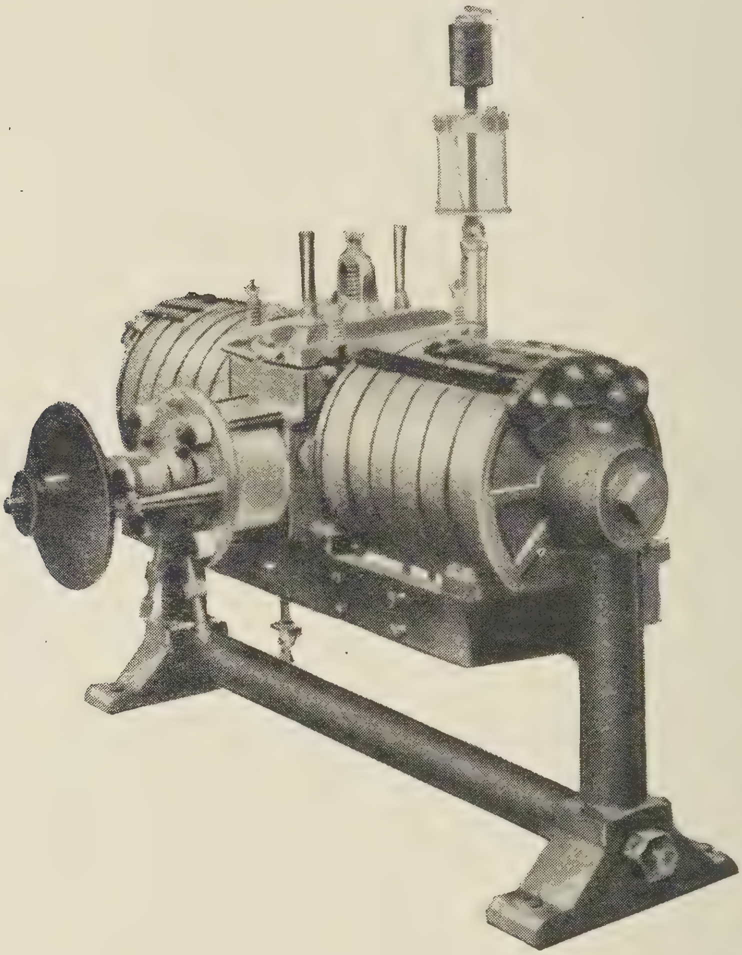


FIG. 94. A practical example of an arc used in a 25 kw. transmitter. A drip-feed reservoir for supplying the arc chamber with some suitable hydrogen compound is seen at the top.

S. G. BROWN'S C.W. GENERATOR.—Fig. 95 (for detailed description see Dr. Erskine Murray's "Handbook of Wireless Telegraphy") shows a method of generating C.W. currents for transmitting devised by **S. G. Brown.** This method works with fair reliability on a 200-volt D.C. supply, and should therefore prove of utility to the amateur. A is a slowly revolving aluminium disc on the edge of which a copper electrode B lightly rests; the degree of pressure between B and A is adjusted by means of a small weight W. R is a resistance, L an inductance, and P is a choke.

METHOD OF PRODUCING LOW-FREQUENCY OSCILLATIONS.—This method was described in "Modern Electrics," April 1912 (343), as follows: "In this apparatus, oscillations are produced from two arcs without the use of the familiar condenser and inductance arrangement. As seen in Fig. 96, use is made of two arcs having their electrodes mounted in holders composed of magnetic material. These holders are mounted on springs E which tend to bring the electrodes together but are held apart by the magnets C and D. The disc R has a number of magnets P mounted around its edge,

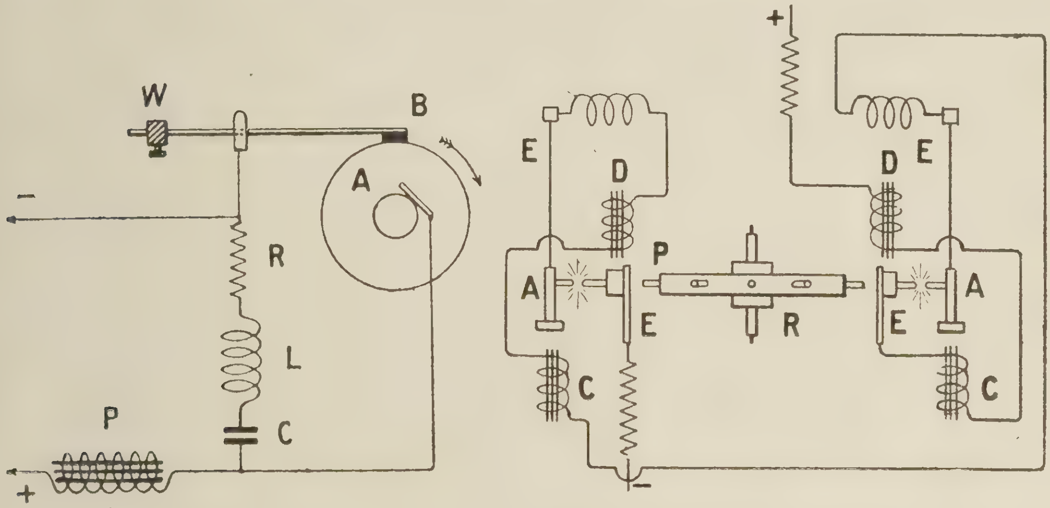


FIG. 95 (left). A C.W. transmitter due to S. G. Brown.
FIG. 96 (right). A circuit for the production of L.F. oscillations, involving the use of two arcs.

and, when revolved rapidly enough, keeps the electrodes in vibration, thus varying the resistance of the arcs and setting up oscillations in the circuit. The oscillations are, however, of comparatively low frequency."

THE MAGUNNA CONVERTER (333).—In 1914 La Société des Télégraphes Multiples took out a French patent covering a method of converting continuous current into alternating, for the production of "Magunna" oscillations for use in Wireless Telegraphy. The method, which is a modification of the Tuning Fork Interruptor (92), is shown in Fig. 97.

An endless belt B is driven slowly in the direction indicated by the arrow by means of a small motor. The tension of the belt can be adjusted by slight displacement of one of the pulley wheels C or D, so that the two rigidly fixed tuning forks F and F_1 are in contact with the belt when it is at rest. The movement of the belt causes the forks to vibrate, causing make and break against the adjustable contacts E

and E_1. Either one or both tuning forks can be employed. In the former case the frequency of the interruptions is equal to that of the tuning fork employed and independent of the speed of the belt. The contact screw, the fork, the primary of a transformer, and a Morse key are all connected in series, and a condenser is connected across the handle of the fork and the contact screw to suppress the spark at breaking. Two forks can be employed simultaneously, and will convert a current of 5 amps. at 220 volts.

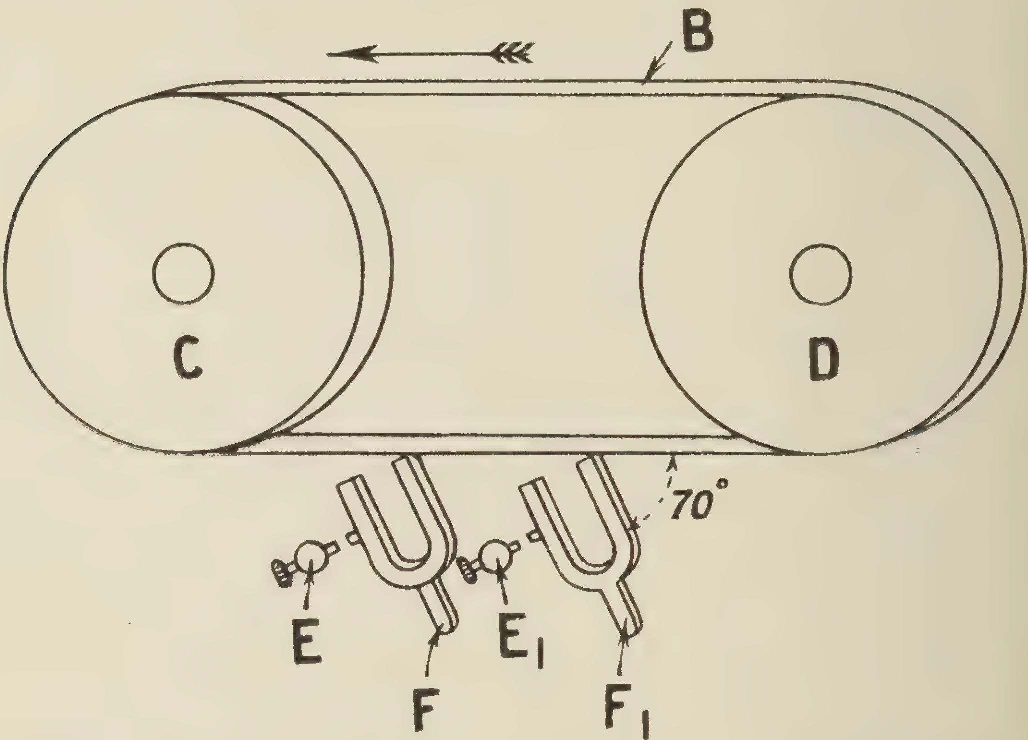


FIG. .97 Diagrammatic illustration of the Magunna Converter, which employs tuning forks as interruptors.

B. SCHWERIN'S METHOD OF GENERATING CONSTANT CURRENT (348).—Although the experiments conducted by **Schwerin** can hardly be said to be directly connected with wireless, they may be of interest, and the author therefore ventures to include a brief description.

Schwerin's apparatus consisted of a porous filter F (Fig. 97A) having a sheet of wire gauze on either side of it, as indicated at S and S_1. This filter was placed between two tubes T and T_1, from which it was insulated by two insulating rings I and I_1; the filter had a thickness of three inches and a surface of 32 square inches, was made of powdered carbon, and had a resistance of 1,000 ohms when used with distilled water.

The best results were obtained however, when using a solution of ammonia. When the latter was passed through the filter, at a pressure of 10 atmospheres, an output of only 0·04 watt was obtained, but on increasing this pressure to 80 atmospheres 2·56 watts were obtained (32 volts, 0·8 amps.). The effect did not depend upon the rate of flow of the liquid, but upon three factors : the nature of the liquid, its pressure, and the porosity of the filter.

FLEMING'S ARC GENERATOR (4D), (888).—In 1914 **Professor Fleming** patented an arc generator (888), shown in Fig. 98. This arc works quite well on a 200-volt D.C. supply, provided only two or three amps. are used and two or three arcs are coupled together in series.

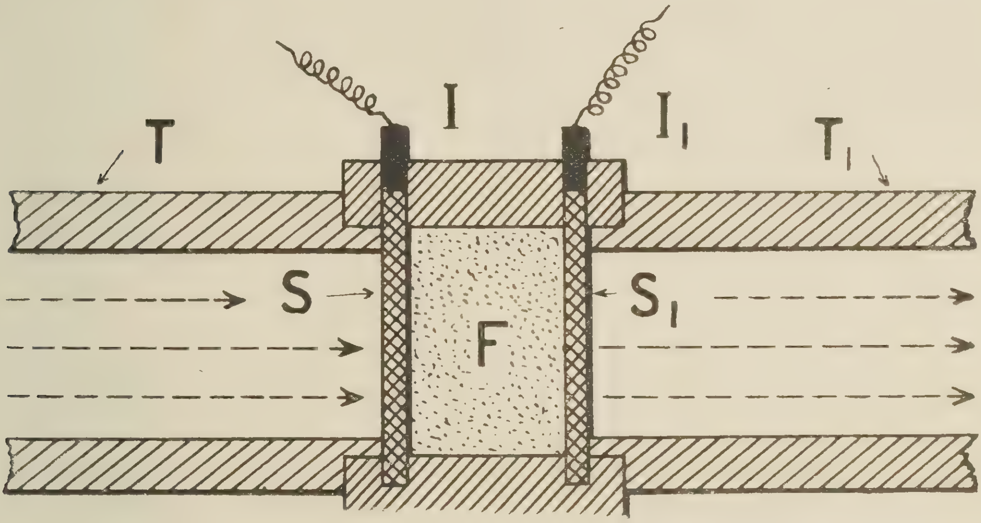


FIG. 97A. A sectional view of Schwerin's Constant Current Apparatus.

The arcs are struck between the copper bottoms of two inverted chambers B and B_1 (the positions of which are adjustable by means of rods R and R_1), and two carbon rods A and A_1. These rods are suitably insulated from a set screw S, the adjustment of which strikes and regulates the arcs.

The carbons are immersed in a bath of thick oil, which, becoming heated by the arc, rapidly volatilizes, so that the chamber is filled with non-oxidizing vapour. The chambers B and B_1 are fitted with small vent holes to allow of the escape of any excess of vapour.

THE ARC GENERATOR OF COLIN AND JEANCE (274), (275), (92).—This is a French generator invented in 1909, and has several points of special interest. It is well known that when an arc burns in air the carbon electrode is slowly burnt away.

When an arc is burnt in a hydro-carbon gas, carbon from the gas is deposited on the carbon, so that it grows as it burns, instead of wearing away. **Colin** and **Jeance** burn their arc in an atmosphere of acetylene and hydrogen, mixed in such proportion that the carbon electrode neither burns away nor grows longer ; consequently, the arc length remains constant

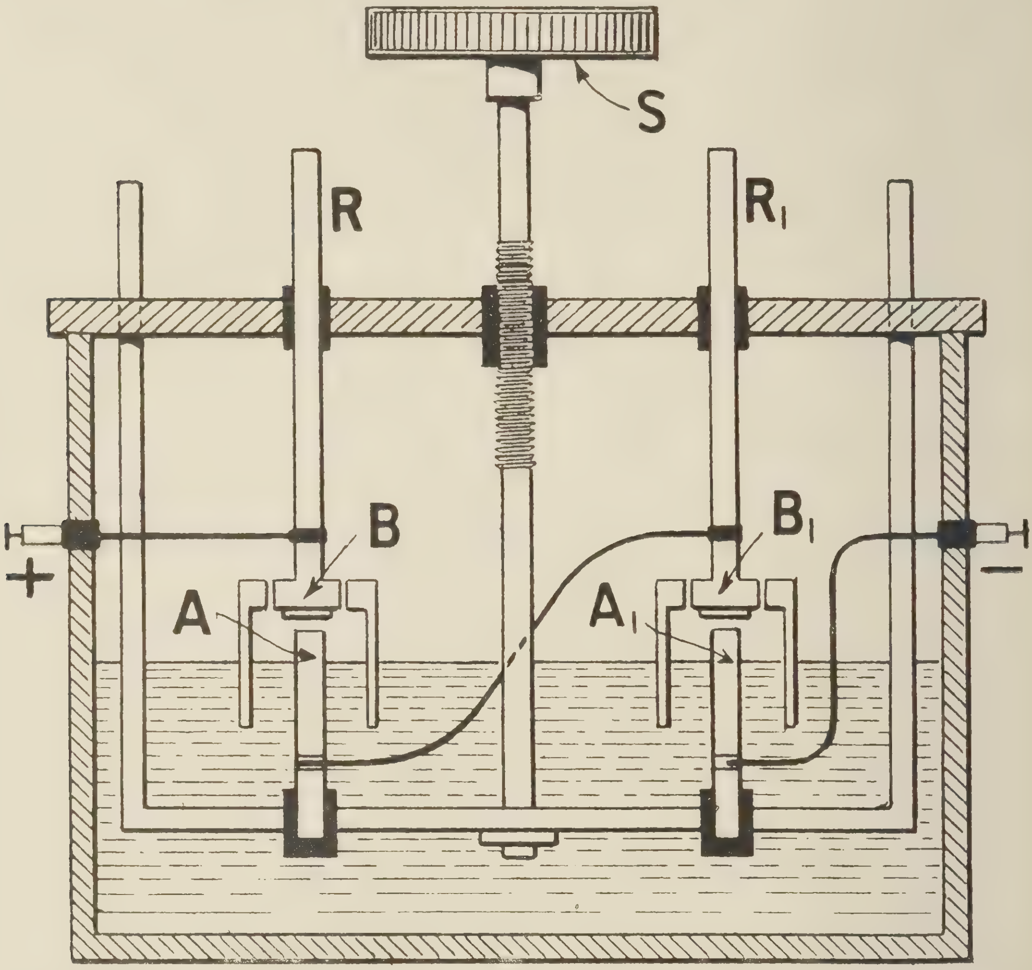


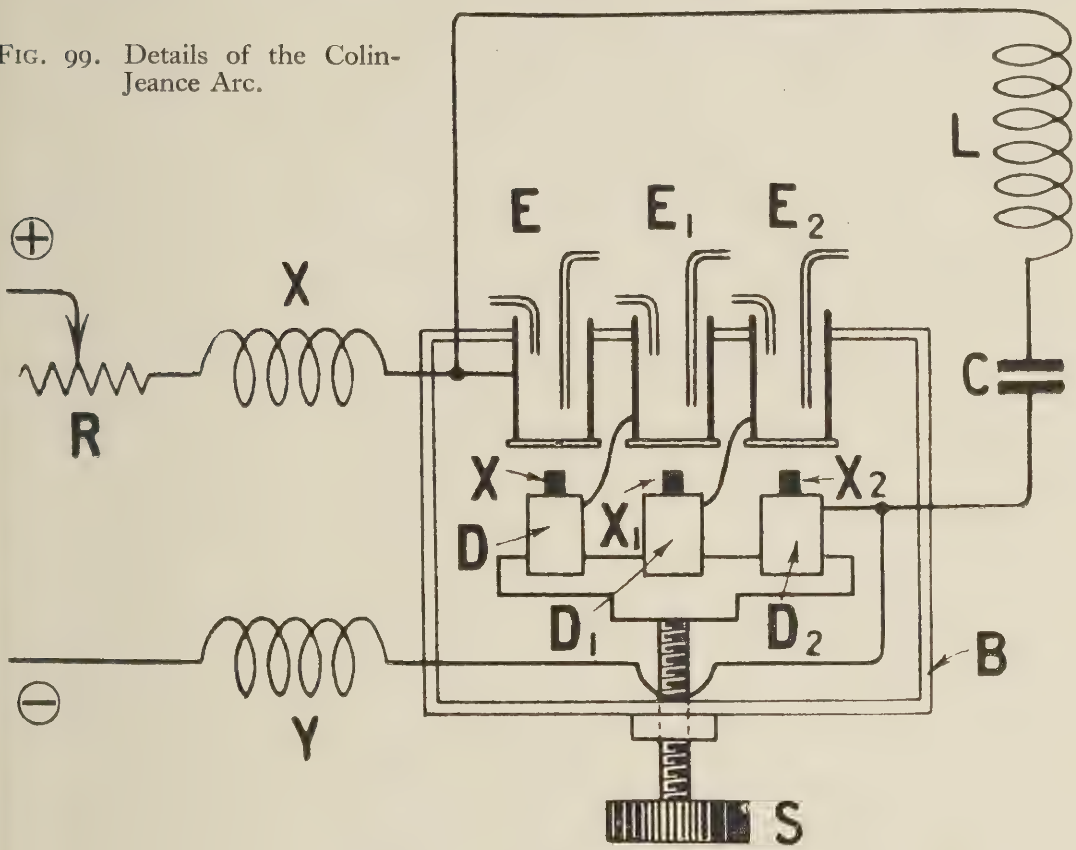
FIG. 98. In Fleming's Arc Generator the arcs are struck between copper electrodes (B, B_1) and carbon rods (A, A_1) immersed in oil.

while the arc is in use. (**C. Fischer** has suggested the employment of hydrogen and acetone (276).)

Fig. 99 represents the Colin-Jeance Arc ; the copper electrodes E, E_1, and E_2 are water-cooled. Three very short thin carbon rods X, X_1, and X_2 form the negative electrodes. These are mounted in solid metal holders D, D_1, and D_2 of large surface area for cooling purposes. The widths of all three arcs are adjusted simultaneously by means of a single set-screw, as at S. The triple arc shown in the figure will work on a 500-volt D.C. supply.

The chief points claimed by the inventors are : The use in the arc of carbons of very small diameter, and the employment of a tuned intermediate circuit placed between the primary oscillating circuit of the arc and the open aerial circuit. The inductance of this intermediate circuit is wound in two coils, which are joined together at their bottoms and their other ends, bridged by a variable condenser. One side is coupled to the primary oscillating circuit of the arc, and the

FIG. 99. Details of the Colin-Jeance Arc.



second coil is coupled to the aerial tuning inductance. In 1914 Colin and Jeance gave an account of some official tests between Paris and Mettray, a distance of 200 km. (92), on a wave length of 985 metres. The arc carbons were only 1·5mm. in diameter ; the arcs were burnt in an atmosphere of acetylene (from calcium carbide and water) and hydrogen (from calcium hydride and water). The supply voltage was 650 volts, and the current across the arcs 4·2 amps.

A. JAHNKE'S ARC GENERATOR.—This is an American variation of the Poulsen system. In this case the arc takes place in liquid alcohol. As with the Poulsen arc, a small condenser and a large inductance are necessary.

DE FOREST (56).*—**De Forest** also devised an arc very similar

* Refer also to **Scheller's** vaporized spirit arc, mentioned on page 179.

to that of Poulsen, the chief difference being that he employed alcohol vapour in place of hydrogen. The arc was arranged in a horizontal position, and alcohol (methylated spirit will answer the purpose) was fed drip by drip on to the heated end of the copper electrode. Here its action was twofold : it evaporated as soon as it struck the hot metal and helped to cool it, and it supplied the atmosphere of alcohol vapour to fill the arc chamber. In order to avoid obtaining an explosive mixture in the chamber when the arc is first struck, it is usual to pour a small quantity of alcohol into the bottom of the chamber and set fire to it just before the chamber is closed. The use of alcohol vapour in the arc chamber in place of hydrogen is now very common. It has been found in use that the carbon electrode does not burn away nearly as quickly with the former as with the latter.

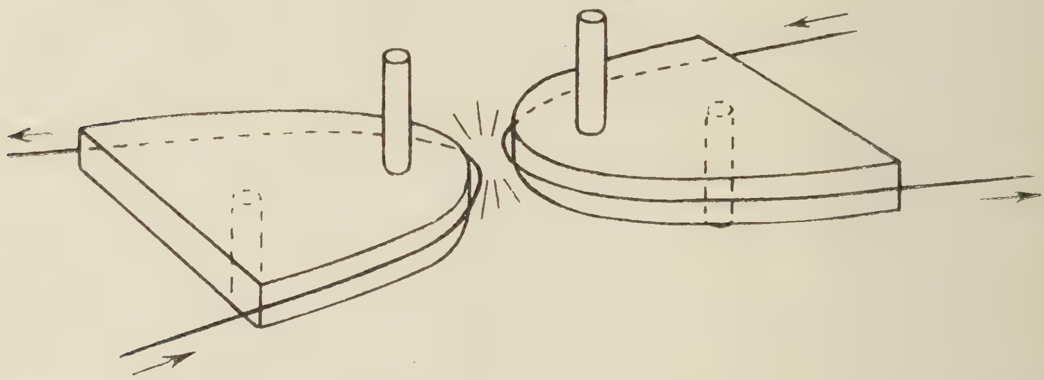


FIG. 100. A form of arc patented by R hmer in which the arc occurs between aluminium wires moving in opposite directions round water-cooled metallic tanks.

RÜHMER'S ALUMINIUM ARC (278), (108).—In 1906 **Ernst Rühmer** took out patents for an arc which took place between two moving wires of aluminium. The arrangement is shown in Fig. 100, which is self-explanatory.

It will be observed that the aluminium wires between which the arc is struck are arranged to move in opposite directions round the edge of two hollow metallic boxes, which are water-cooled.

DUBILIER'S ARC.—**Dubilier** invented an arc (280), (281) which can be used either in hydrogen or alcohol vapour.*

Fig. 101 shows the arc in section, and is taken from Mr. Coursey's book (108). The arc is struck between a solid carbon cathode C and a heavy plate of hard phosphor-bronze B, which acts as the anode. The metallic chamber M, containing the arc, is fitted with flanges for cooling purposes, and

* See also Ref. 164. Arc. patented by Amalgamated Radio Co.

the arc is fed with alcohol from a tank T. Tests made with this arc between Seattle and Tacoma, a distance of 30 miles, in 1911, were most satisfactory. Very clear speech was received, and the Government Station at Tatoosh, 128 miles distant, picked up messages on one or two occasions (281).

E. F. HUTH'S ARC (283), (892).—In 1909 **Dr. Huth,**

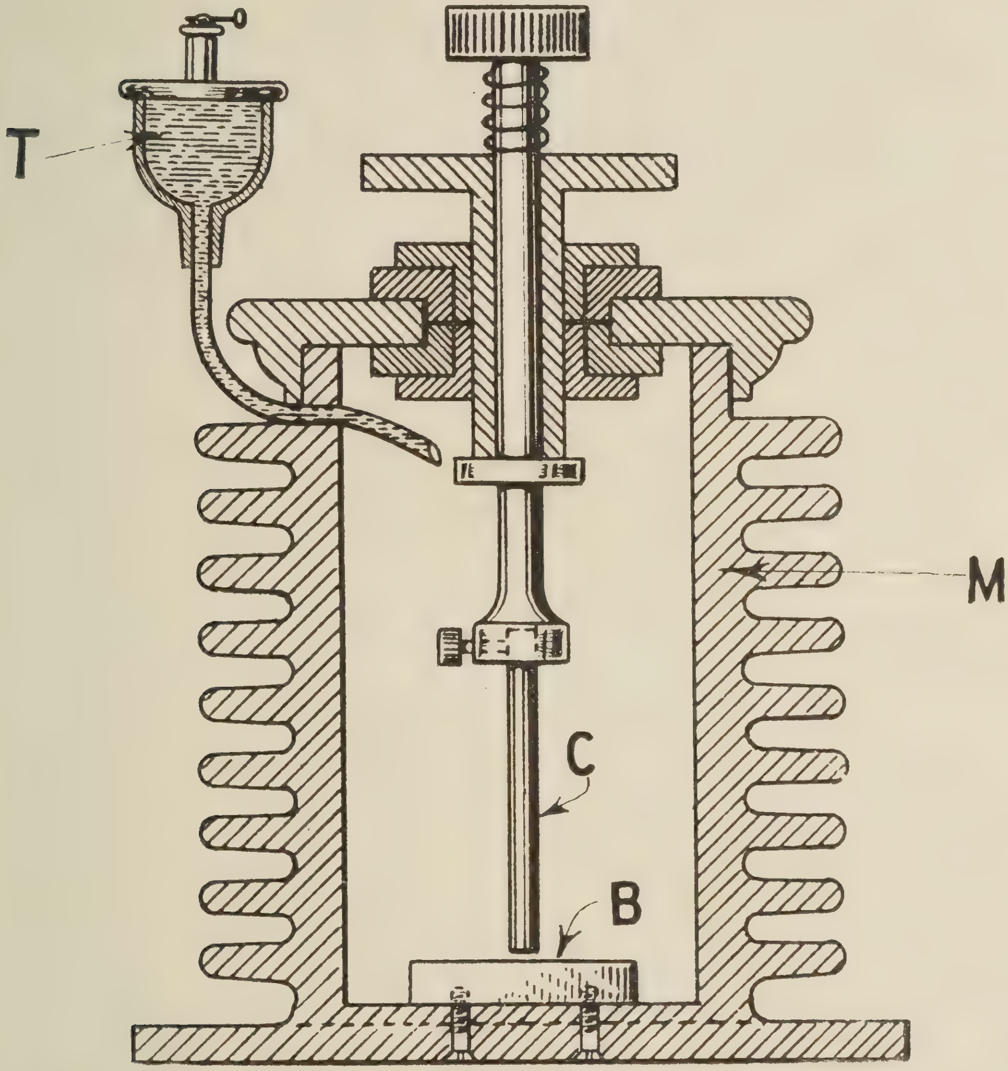


Fig. 101. In Dubilier's Arc, electrodes of carbon and of copper are used.
Reproduced from P. R. Coursey's book "Telephony without wires" by courtesy of the Wireless Press.

of Berlin, patented the arc shown in Fig. 102. It is only intended to deal with small power for ranges up to 50 miles. Both electrodes are made of carbon in the form of tubes having conical ends. The upper electrode projects into the lower. The arc is started at a point A where the electrodes are nearest to one another, and is driven outwards by the heated air. This action has a similar effect to a magnetic or other blast.

The intensity of the oscllations is greatly increased if the electrode D is partly filled with methylated spirits or alcohol. Huth also employed a winding round the upper electrode to make the arc rotate. The generator will work steadily on as low a voltage as 220, and with a current of only one ampere, for experimental purposes.

Mercury Vapour Arcs and Continuous Oscillation Spark Generators (376).

The Cooper-Hewitt Mercury Oscillator (4D), (284), (285), (286), was patented in 1903, and in further patents in 1905 (849).

Fig. 103 shows the mercury arc and the connections employed. M is an exhausted bulb made of glass or silica. In

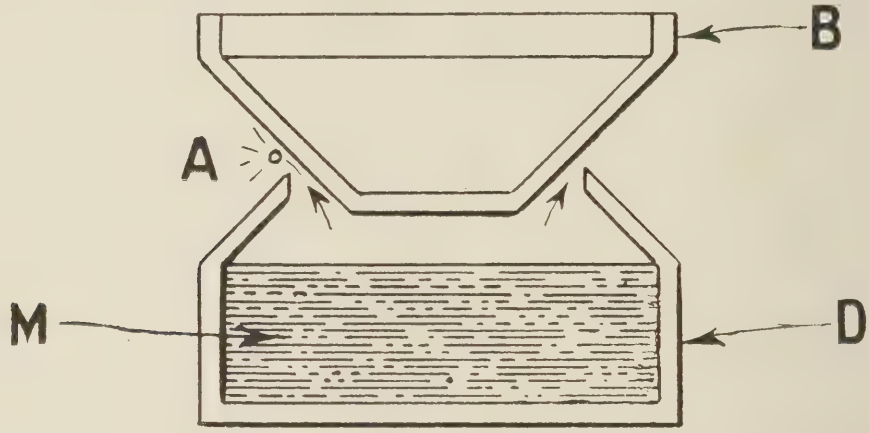


Fig. 102. A type of arc suitable for low powers, patented by Dr. Huth.

the two small hollows round the electrodes T and T_1 are two little pools of mercury. The arc is struck between the electrodes by momentarily tilting the bulb on one side. This causes the mercury to run over from one electrode to the other, and so causes a short circuit. A large current at once flows through it, and vaporises it. The arc then continues through the mercury vapour. When a shunt circuit, consisting of an inductance and condensers C and C_1, is placed across the electrodes T and T_1 the arc sets up and sustains high-frequency oscillations.

Simon and Reich Mercury Vapour Arc.—**T. Simon** and **M. Reich** (290), (50) carried out some very similar experiments in 1903, using very similar connections.

Liebowitz Mercury Generator.—**B. Liebowitz** (287), (108) about 1914 constructed a special form of mercury vapour tube for the production of steady oscillations (see Fig. 104).

The tube had two negative electrodes (or cathodes) K and K_1, and a common anode A, made of iron. The oscillating circuit LCC_1 was connected across the two negative electrodes. Resistances R, R_1, and chokes X, X_1 are placed in each of the negative leads. A supply current of about 4,000 volts was employed, and small capacities were used in the oscillation circuit.

FREDERICK K. VREELAND'S MERCURY ARC OSCILLATOR (92), (288), (289), (108), (375), (901).—In 1906 **Vreeland** succeeded in producing high-frequency oscillating currents from a D.C. supply with a mercury arc of special construction. His tube T, Fig. 105, was fitted with two carbon anodes A, A_1,

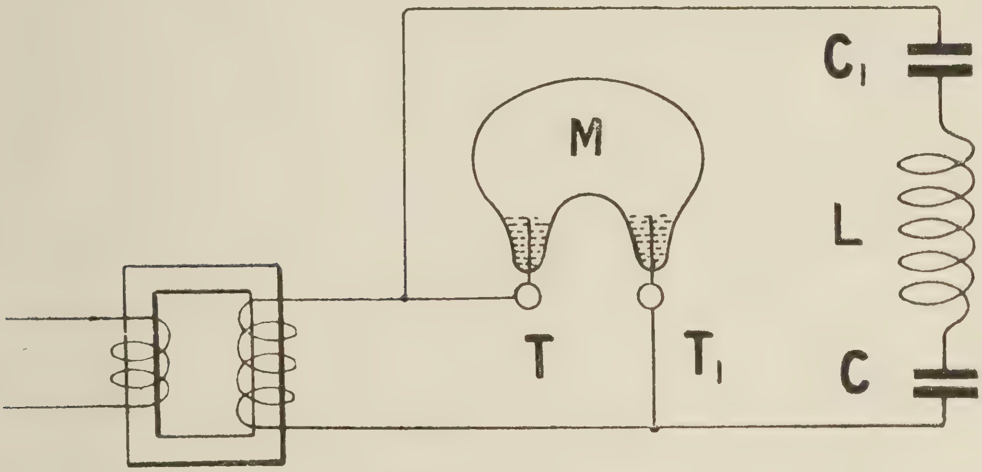


FIG. 103 illustrates the principle of the Cooper-Hewitt Mercury Arc.

one on each side of the tube, and one mercury cathode X. The anodes are in parallel, each having a separate resistance and choking coil.

The two anodes are connected to an oscillation circuit, in such a way that the magnetic fields of the inductances L, L_1 act directly upon the mercury vapour and cause a deflection of the cathodal stream towards one or other of the anodes. Oscillations are maintained quite steadily by the discharges of the condensers through the inductance coils.

SOCIÉTÉ FRANÇAISE (MERCURY ARC).—In 1915 the Société Française Radio-Èlectrique patented a mercury arc generator (720).

THE "POINTOLITE" LAMP AS A SOURCE OF H.F. OSCILLATIONS (539).—The General Electric Company manufacture a lamp primarily intended for purposes of illumination. It consists of a tungsten arc in an inert gas. If one of these

lamps be shunted by a circuit containing an inductance and condenser it becomes the source of high-frequency oscillations.

MARCONI'S HIGH-SPEED ROTATING DISC DISCHARGER—References (294), (4D), (92), (93), (108), (875), (876).—Patented in England, April 11th, 1907 (860), (862), (893), and (894). Patent filed in America in 1908 (327).

In 1906 **Marconi** produced practically continuous and very powerful oscillations by means of his rotating disc discharger (Fig. 106A).

W is an insulated disc with a smooth surface, which is rotated at high speed between two other rotating discs, W_1 and W_2, also having quite smooth surfaces. L_2 and L_3 are in-

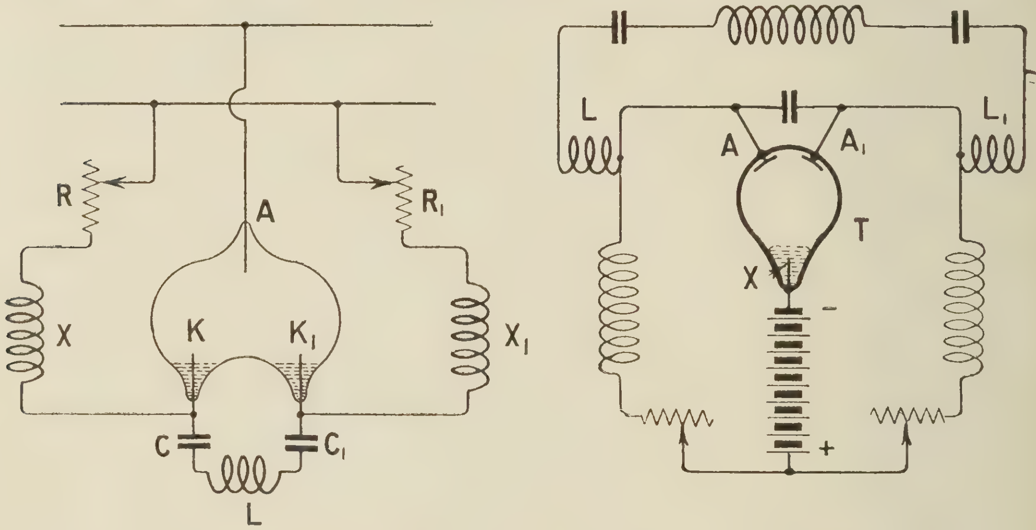


FIG. 104 (left). In the Liebowitz Mercury Arc there are two negative electrodes across which the oscillatory circuit is connected.
FIG. 105 (right). Vreeland's Mercury Arc Oscillator has two anodes.

ductances, C and C_1 are condensers. A and B are the leads from a high-voltage direct current supply, K and K_1 are chokes. C_2 is a condenser in series with an inductance coil L, which is coupled to the A.T.I. L_1.

When the condensers are charged to a sufficiently high potential a discharge takes place between W_1, W_2, and main disc W, and oscillations are produced in the main disc circuit which are continuous or almost continuous.

Marconi explains the action as follows (92):

" Assuming that the generator gradually charges the double condenser, and that the potential of the side discs becomes positive on the left and negative on the right, then, at a certain instant, this potential causes a discharge across one of the small gaps between a side disc and the main disc. Suppose this to take place at the right-hand gap, this discharge produces an

oscillation through the inductance coil and condenser, and this oscillation on reversing tends to pass from the main disc across the gap, hitherto not bridged by a discharge, since the condenser on that side is already charged to an opposite potential. Thus, at each reversal of the oscillation in the inductance coil, energy is picked up from the two series condensers, which are kept charged by the generator. If the main disc were kept stationary, an ordinary arc would at once occur across the gap between the discs and oscillations cease."

COURSEY'S ROTARY SPARK GAP.—In his book, "Telephony without Wires," **P. R. Coursey** describes a rotary spark of the smooth disc type, particularly suited for experi-

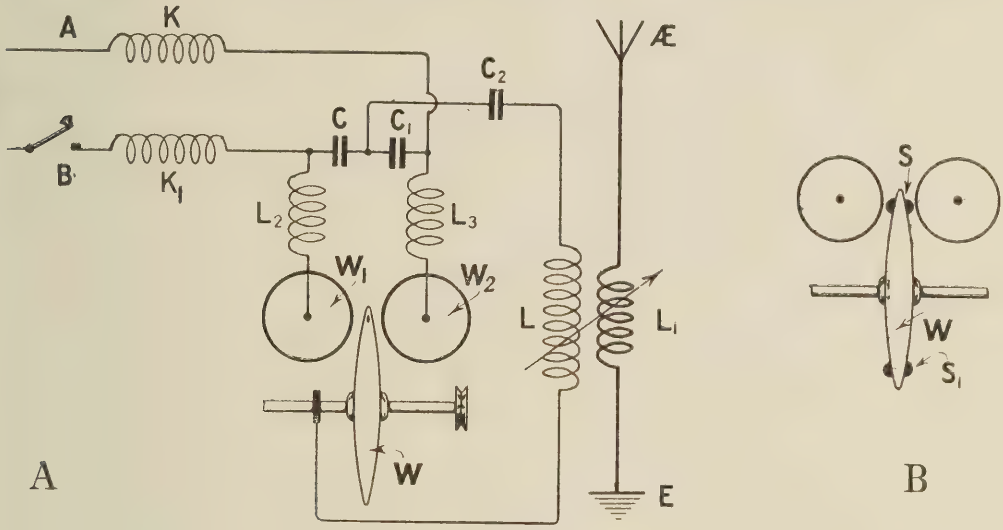


FIG. 106A. The circuit of Marconi's Rotating Disc Discharger.

FIG. 106B. A modification of Marconi's Disc Discharger in which the main disc is provided with a row of studs on each of its sides.

mental work where only small powers are employed. There is only one disc, which revolves between two fixed metallic ball electrodes, which may (for increased powers) be water-cooled.

Marconi has several variations of the use and construction of his spark gap. The disc discharger can, for instance, be employed on an A.C. supply.

One variation is shown (Fig. 106B). A row of small studs S S_1 is arranged around each side of the disc. These interrupt the C.W. and make it readable on a crystal detector.

MARCONI'S SYNCHRONOUS DISC DISCHARGER (92), (875).—This arrangement is shown in Fig, 107. The studded disc W is run synchronously with the low-frequency alternator, the disc usually being mounted on the shaft of the former. The number of studs S must correspond with the number

of poles, and the disc must be so arranged that the discharge takes place near the peak of the voltage wave of the transformer. Dischargers on these lines have been built to take as much as 300 kw.

Fig. 108 is a photograph of Marconi's Timed Disc, reproduced by the kind permission of the Marconi Company.

In 1918, using this disc, their signals from the Marconi Transatlantic Station at Carnarvon were picked up for the first time in Sydney, Australia (right round the world).

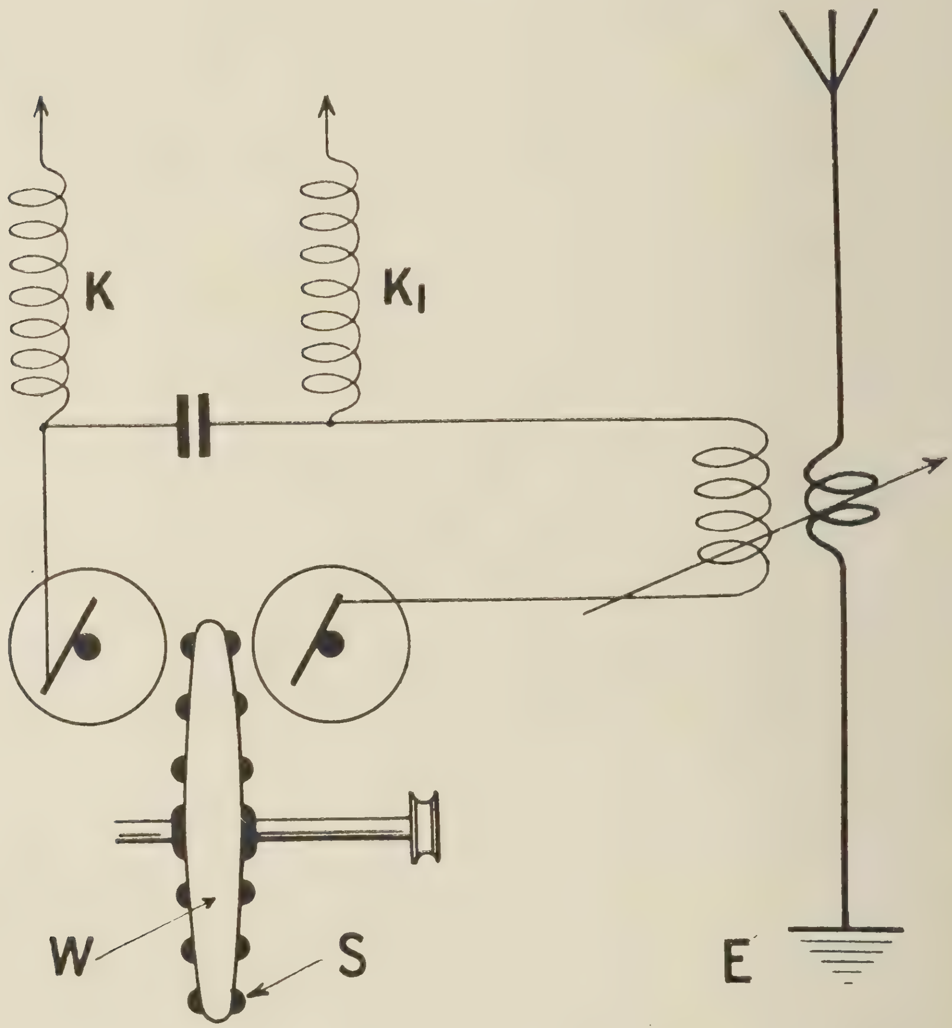


FIG. 107. The studded disc W in Marconi's Synchronous Disc Discharger is revolved synchronously with the alternator supplying the power for the circuit.

F. MAJORANA'S ROTARY GAP (895).—In 1913 **Majorana** patented a rotary gap which employs two rotating discs similar to those used by Marconi, but placed at right angles to one another. The edges of the discs may be covered with platinum, or cleaned by brushes during rotation.

FERRIÉ'S ROTARY DISCHARGER.—**G. Ferrié**, working in conjunction with **Francque** and **Brenot** (92), has constructed a rotary discharger and obtained good results up to 10 kw. A similar discharger has been installed at the Sainte Marie W.T. Station by Petit.

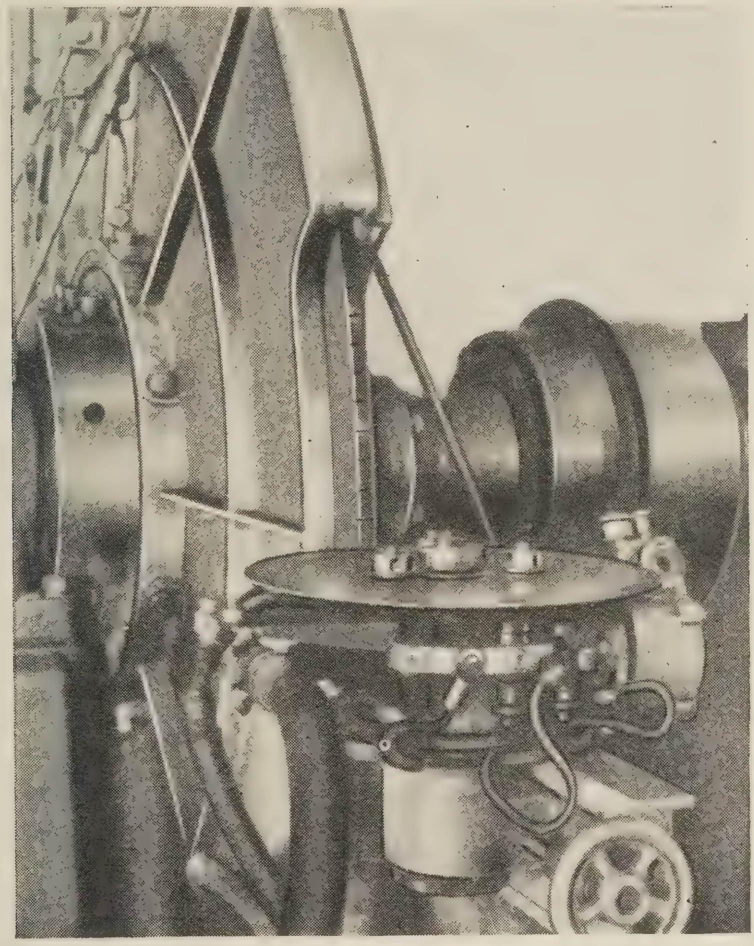


FIG. 108. Photograph of Marconi's Timed Disc by means of which signals were for the first time transmitted round the world in 1918.

FESSENDEN'S CAPACITY CHANGER.—In 1905 **Fessenden** took out an American patent (325) for the production of high-frequency electrical oscillations, by means of his capacity changer, *i.e.* a kind of rapidly-rotating variable condenser.

CHAPTER XIII.

Various Types of Microphones

THE carbon microphones which are in use at the present day are, speaking generally, modifications of Hughes' Microphone, and, in the same way, we can say that our modern telephone receivers are modifications of Bell's early magnetic receivers.

Of the numerous microphones which were designed after the work of Hughes and Edison we will describe only a few to indicate the lines along which this instrument has been developed.

Early Types of Microphone.—The earliest forms employed contacts between small carbon rods held loosely between carbon blocks, and fixed on sounding boards. The

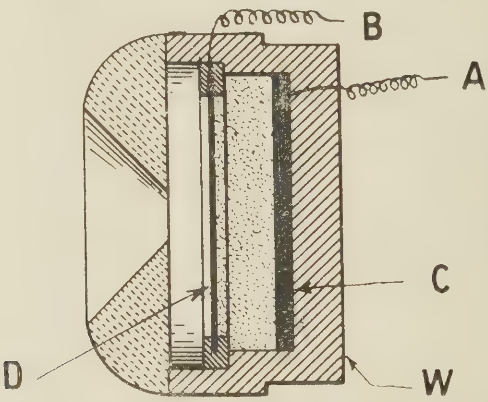


Fig. 109. Modern carbon granule microphones are elaborations of that invented by Hunnings, which is illustrated here.

best known of these were designed by **Crossley, Ader,** and **Gower.**

Berliner's Microphone.—**Berliner's** Microphone, of 1877 (1), (18), departed somewhat from the earlier types in design. It had only one microphonic contact, and that was between a small block of carbon, attached to the centre of a diaphragm, and a second small piece of carbon attached to a kind of pendulum, which hung down just behind the diaphragm a[illegible] pressed lightly against the first piece of carbon.

Blake's Microphone (1).—This microphone, whic[illegible] been very widely used in this country, is of simil[illegible] but the contacts are arranged on springs and neithe[illegible] is directly attached to the diaphragm.

Edison's Early Form of Microphone (1).—I[illegible] ment the battery current is passed through a [illegible]d

carbon mounted against a solid metal back and having a platinum plate resting against its opposite surface. The pressure of this plate against the carbon is controlled by a diaphragm, the vibrations of the latter being conveyed to the plate by means of a tiny knob of aluminium about the size of a split pea, the flat surface of which is attached to the platinum plate, and so arranged that its rounded surface touches the diaphragm.

HUNNINGS' TRANSMITTER (1).—In 1878 **Hunnings** (an English clergyman) invented the transmitter shown in Fig. 109, the forerunner of our modern carbon granule micro-

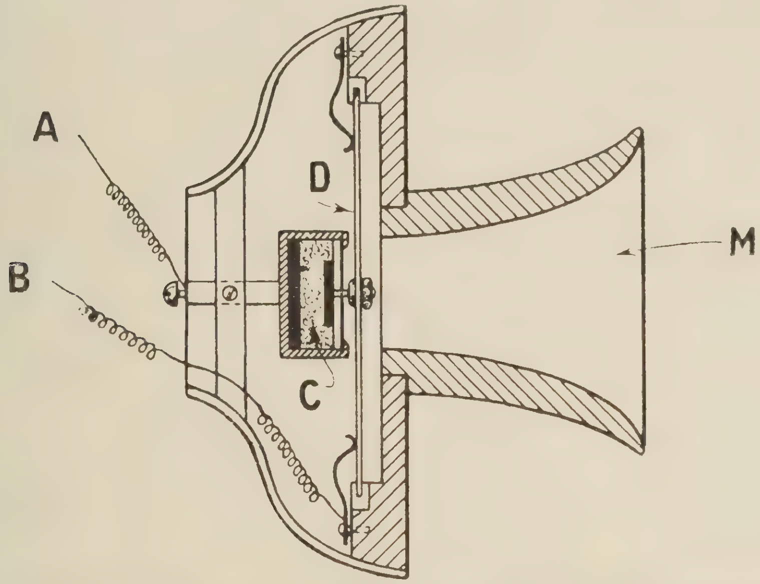


FIG. 110. Shows the essential details of the Post Office pattern solid-back Microphone.

phones. It consists of a small chamber, about $2\frac{1}{2}$ins. diameter, in a block of wood or ebonite W. At the bottom of this chamber is fixed a plate of carbon C, to which connection is made by wire A. The space in front of this plate is loosely packed with granulated carbon particles, so as to almost fill the space between the carbon block C and a platinum foil diaphragm D, to which electrical connection is also made, as shown at B, in order that the current may pass through the mass of granules on its way from the battery through the receiving telephone.

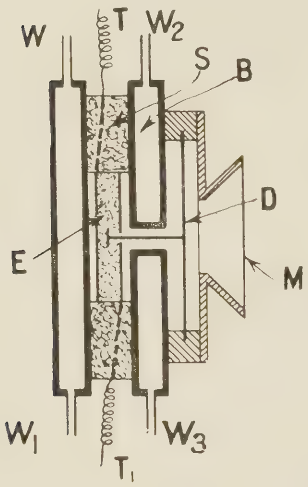
It is unnecessary to deal at further length with the early development of the microphone in this work, and we will pass on to some of the instruments in use to-day for line and radio telephony.

POST OFFICE PATTERN SOLID BACK MICROPHONE.—Fig. 110 shows the construction of the instrument in general use in

our " Subscribers' " land line telephones. This type is occasionally used in conjunction with valve-transmitting sets for Radio-telephony. It will safely carry a current up to about one ampere, but above this the granules become heated and tend to pack.

M is the mouthpiece, C the carbon granules, D the diaphragm, connections being made as shown at A and B.

In order to deal with large currents, many different microphones have been invented. Amongst others, **Marzi** (108) invented a carbon powder microphone to deal with comparatively large currents. In this a stream of carbon granules continually pour out of a container (which forms one electrode) on to a small carbon plate on the end of a short lever arm (which forms the other electrode).



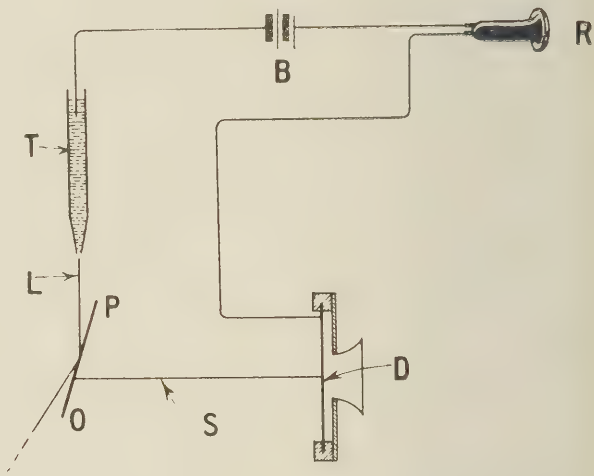


FIG. 111A (left). A drawing in section of Fessenden's Carbon Granule Microphone, which is designed to carry heavy currents.
FIG. 111B (right). Illustrates the principle of Jervis-Smith's Liquid Microphone.

The lever arm is pivoted near to its centre, and its free end is made of iron, and is poised between the poles of an electromagnet, the windings of which are placed in a microphone circuit actuated by only a small current. On speaking into the microphone the lever moves between the magnetic poles, and the electrodes are brought close to and further from one another, in response to the voice. This, in turn, alters the resistance of the falling granules.

FESSENDEN'S MICROPHONE.—In 1906 **Fessenden** (56) invented a carbon grain microphone for wireless which he claims will carry a current of 15 amps. without packing. Fig. 111A shows the construction of the instrument. The carbon grains are held in a small chamber E, cut in the centre of a disc of soapstone S. Two platinum electrodes at the back and front of the chamber are water-cooled. A small rod passes

through a small hole in the front water-cooling tank and electrode, connecting the diaphragm D to a small spade or plunger in the centre of the chamber E which is only half filled with carbon grains.

COLLINS' MICROPHONE.—In 1910 **A. F. Collins** invented a carbon granule microphone capable of dealing with moderately large currents.

DUBILIER'S WATER-COOLED RELAY MICROPHONE (108), (356), (357).—This instrument was invented by **W. Dubilier** in 1911* This microphone can pass 700 watts with clear articulation, and can be employed as a "Repeater" for relaying the speech

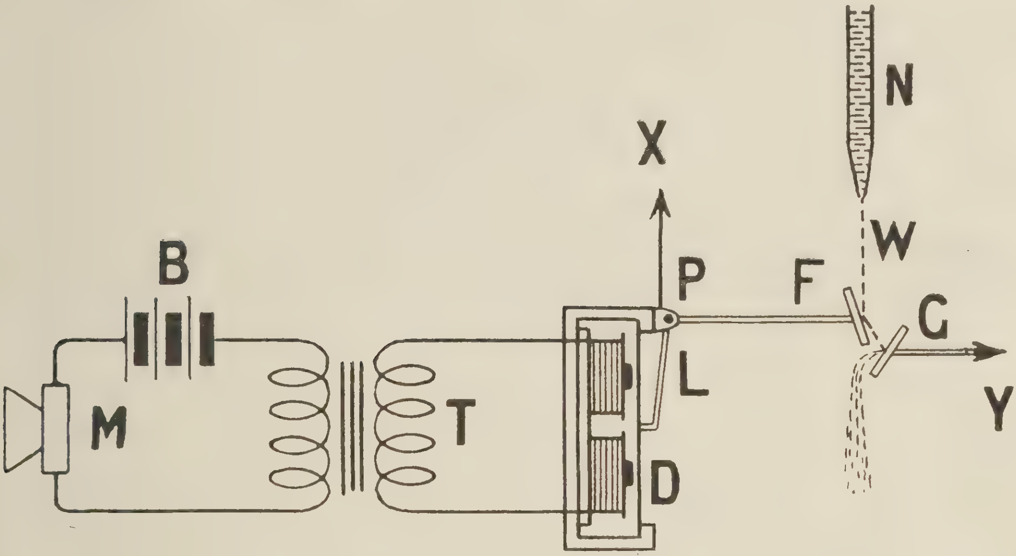


FIG. 111C. Shows the principle of Vanni's Liquid Microphone. The device is connected to the external circuit at the points marked X and Y.

from a land line on to a radio-telephone transmitter. Fig. 112 is a photograph of the instrument, reproduced from "Nature," April 2nd, 1914. (By Courtesy of Messrs. Macmillan & Co.

Fig. 112A is a diagram showing its construction. D is an insulating ring, which carries in its interior two supports, A and A_1, for a second ebonite insulating ring R. In the interior of this second ring are two cups, T and T_1, packed with carbon granules, and, in the space around these cups, a system of water-cooling is arranged, led in and out by tubes H and H_1, as shown. The granules are held in the cups by mica discs. The current to be modulated by the voice is led in by wires X and X_1, through two ferrotype diaphragms V and V_1, and thence to the carbon granules by means of platinum rings P and P_1 attached to the diaphragms.

* **R. A. Fessenden** invented a telephone relay, which he employed in his 1906 experiments, described in chapter XIV.

M and M_1 are two permanent magnets. Around these magnets are the windings shown in Fig. 112A. These are connected in series with an ordinary microphone and a small battery. When the microphone is spoken into, the two diaphragms V, V_1 move simultaneously in opposite directions, so that there is nearly twice as much variation in the conductivity of the granules as that obtainable with a solid back microphone.

GOLDSCHMIDT'S PARALLEL MICROPHONES.—**R. Goldschmidt** took out a British patent (No. 15915, 1912) covering a method

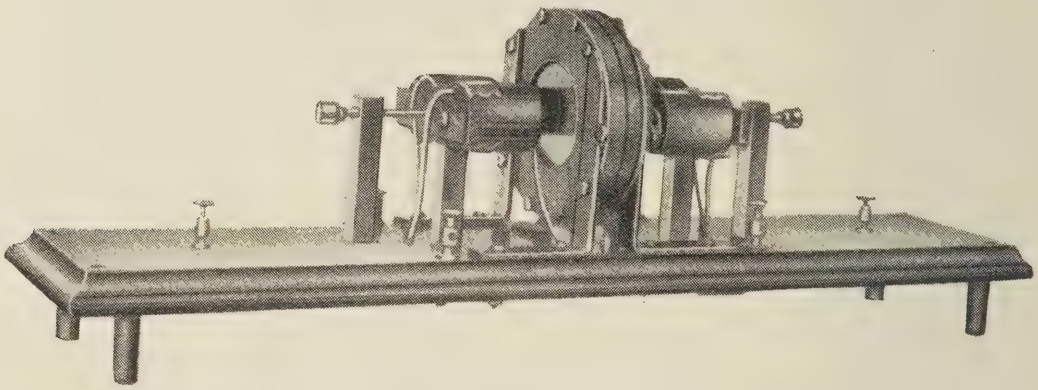


FIG. 112. Dubilier's Water-cooled Microphone can be employed in a relay circuit where it can handle energy up to 700 watts with safety.

of working with several microphones connected in parallel (355).

LIQUID MICROPHONES

JERVIS-SMITH'S LIQUID MICROPHONE.—Probably the first liquid microphone was invented by **F. J. Jervis-Smith**, in 1879, in pre-wireless days (359), (1), (92). The principle of this microphone is shown in Fig. 111B. L is a stream of liquid conducting a current in a circuit comprising a battery B and telephone receiver R, and a pivoted conducting plate P, against which the jet of liquid strikes. When one speaks near to the diaphragm D, which is attached by a fine rod S to the plate, the angle of the plate is altered and the length of the column of liquid is varied, with consequent changes in its resistance.

G. VANNI'S LIQUID MICROPHONE (357), (56), (108), (838).—Fig. 111C and Fig. 113A show **Dr. Vanni's** microphone, which is based on the same principle as that which was employed by Jervis-Smith. A small jet of acidulated water W (Fig. 111C)

passes through nozzle N on to a small plate F attached to diaphragm D. It splashes off this on to a fixed plate G. Every movement of the diaphragm alters the resistance of the liquid between the two plates. The diaphragm may either be operated on directly by the voice or it can be connected to a distant telephone circuit by means of the electromagnetic device shown on the diagram.

In 1912 Vanni, employing a Moretti Arc (see Chap. XI., Fig. 88A), and controlling the radiation with his liquid micro-

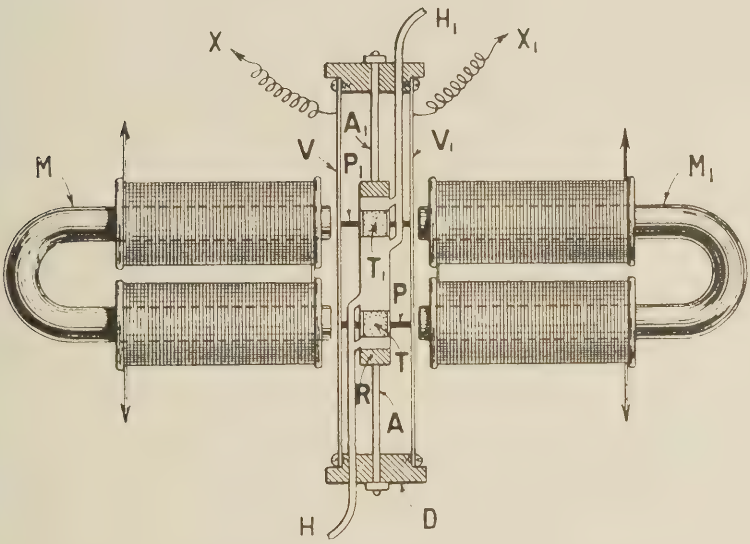


FIG. 112A. Shows the constructional details of the Dubilier Microphone illustrated on the previous page.

phone, transmitted and received clear speech (very free from distortion) first between Rome and the Island of Ponza 120 km., then from Rome to Maddalena 260 km., to Palermo 420 km., to Vittoria 600 km., and finally between Rome and Tripoli, a distance of 1,000 km. (357).

CHICHESTER BELL'S SOUND-SENSITIVE JET.—In 1886 **Chichester Bell** (92), (108) discovered that a jet of liquid was extremely sensitive to sound. The effect of the sound waves upon the jet was to make the jet swell out and form into isolated beads a few inches down the stream. The "Bell" effect is shown on Fig. 113B.

Q. MAJORANA'S LIQUID MICROPHONE.—**Q. Majorana** (56), (108), (362–364), (165),* made use of this effect in his liquid

* For **Majorana's** British patents see Refs. (364), (165) and (838).

microphone, shown at the right-hand side of Fig. 113B. Tube A is in this case fitted with a small elastic partition near its end. This is attached to a rod leading from the diaphragm M. Two small rods or plates E and F are arranged near the bottom of the column, just above the place where it forms into drops. These rods just enter the column a very little way, and are connected to the circuit conveying the current, which we wish to control by the voice.

Now, on speaking in front of M, vibrations are conveyed to the liquid by the rod from the diaphragm, and a sort of wave-motion takes place down the column, as shown in the diagram, its form depending on the voice, so that the electrical resistance of the column between the two rods is continually

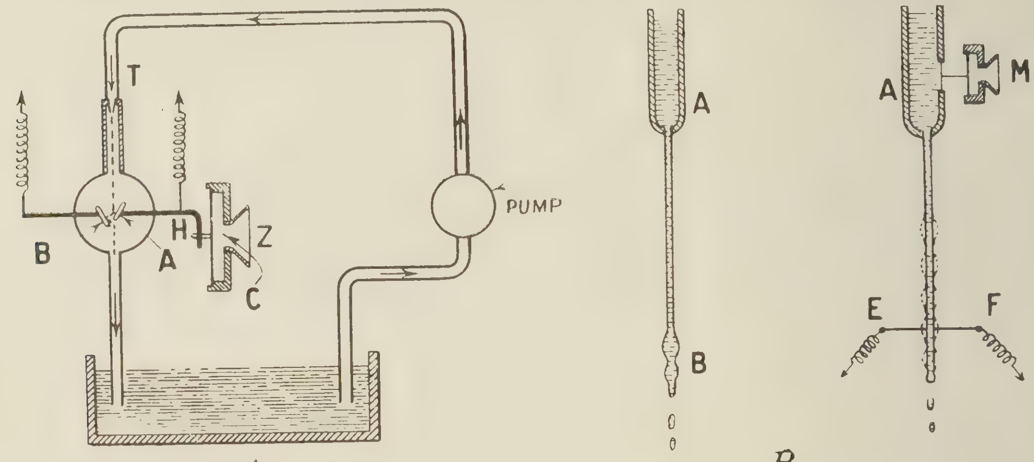


FIG. 113A. Indicates the manner in which the continuous stream of liquid in Vanni's Microphone is obtained.
B. Illustrates the effect of sound waves on a jet of liquid (left) and the application of this "Bell" effect in Majorana's Liquid Microphone (right).

changing in exact accordance with the sound waves acting on the diaphragm.

The conductivity of the column can be varied within certain limits by the size of the hole in the tube, and by the character of the liquid employed, whether it be acidulated water, soda solution, salt water, mercury, etc.; also by adjusting the distance between the rods E and F.

In 1906 Majorana (92), using his liquid transmitter, as above described, telephoned by wireless between Monte Marie and Trapari (Sicily), 313 miles.

SYKES' LIQUID MICROPHONE.—In 1914 **A. F. Sykes** and **S. Ford** patented a liquid microphone (365) involving quite a different principle. A steady stream of water is employed issuing from a special form of non-splash jet* (Fig. 114).

* One method of obtaining a non-splash stream of liquid, *i.e.* one which will not splash when it falls upon a solid object, is to cover the nozzle with a fine mesh of plaited glass fibres.

This stream flows between two electrodes B and B_1 in a similar manner to that employed by Majorana.

The conductivity of the water is varied by the voice in a very ingenious manner. T, Fig. 114, represents a tube containing a solution of concentrated electrolyte of comparatively high conductivity. D is a diaphragm which controls the flow of a stream of this concentrated solution into the main water stream X.

The resistance of the liquid column between the electrodes is thus controlled by the voice. Quite a small instrument will carry a considerable amount of high-frequency energy, without overheating (108).

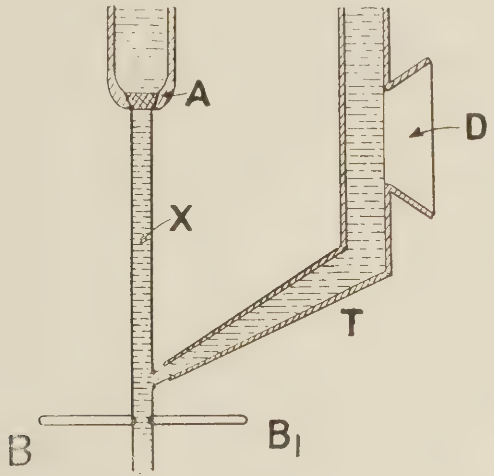


Fig. 114. In the liquid microphone of Sykes and Ford the resistance of the column of liquid X between the electrodes B and B_1 depends on the speech-controlled flow of the electrolyte from the tube T.

F. J. Chambers' Liquid Microphone (366), (92), (56).—Fig. 115 illustrates the principle of this microphone, invented in 1910. A small jet of acidulated water passes through a nozzle C, and plays upon the underside of the diaphragm. When the diaphragm vibrates there is an alteration in the resistance of the liquid at this point. This microphone is capable of dealing with 400 watts, and gives particularly clear articulation free almost entirely from resonance effects. This is due to the pressure of the jet on the diaphragm damping its free vibration, so that it can only follow the vibrations impressed upon it by the voice.

Another means of modulating the radiation from a radio-telephony station is by alterations in tuning achieved by the employment of a condenser microphone.

R. A. FESSENDEN'S CONDENSER MICROPHONE.—This instrument is very similar in construction to Dolbear's electrostatic telephone receiver, described in Chapter II. (Fig. 8). It consists of a metal diaphragm in close proximity to but insulated from a fixed back plate of metal.*

Fessenden showed that it could be placed in series with the aerial between the A.T.I. and earth, or in parallel with the A.T.I.

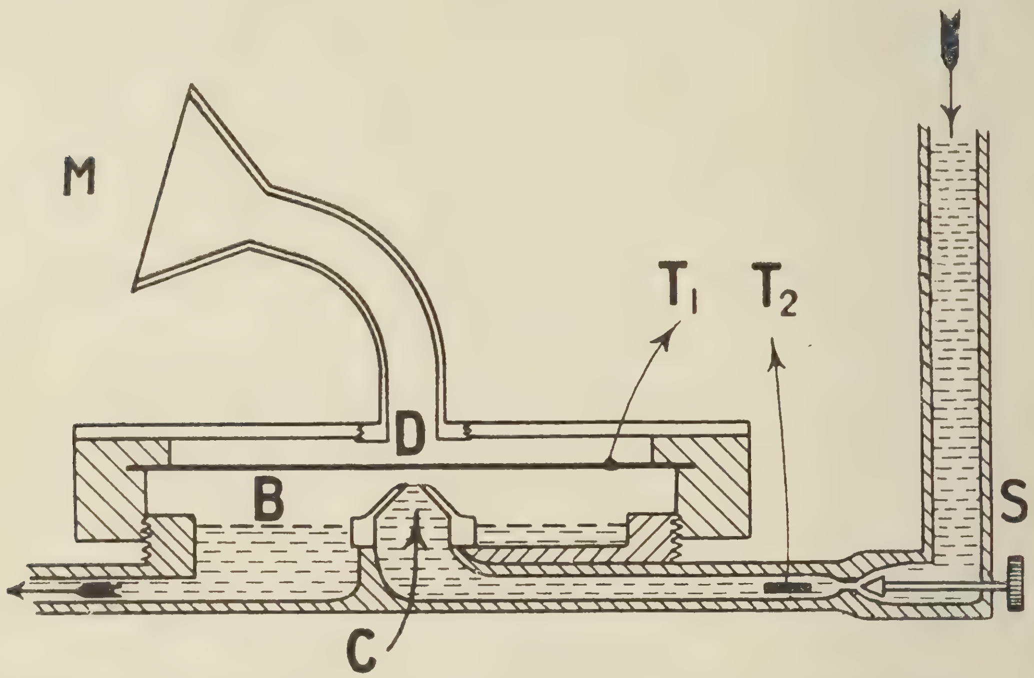


FIG. 115. A diagrammatic representation of Chambers' Liquid Microphone.

W. BURSTYN'S MULTIPLE CONDENSER MICROPHONE.—**W. Burstyn,** in 1909, patented the arrangement shown in Fig. 116 (367), (368), (108). This instrument is really a kind of "Talking Condenser." It consists of a number of diaphragms D connected in parallel. These are controlled electrostatically by the varying voltages obtained from the secondary of a transformer T, in the primary circuit of which a carbon-granule microphone M and battery B are connected. The closed oscillatory circuit from the C.W. generator is inductively coupled to inductance L.†

* The action of this condenser is described at some length in **P. R. Coursey's** book, "Telephony without Wires."

† Reference should also be made to the condenser microphone of the Western Electric Co. (Ref. (1010). Also to Ref. (1037).

Alexanderson's Magnetic Microphone Relay (108), (380 to 383).—In 1911 **E. F. W. Alexanderson** patented a method for controlling high-frequency currents (see Fig. 117). W is a winding round both the two iron cores O and P. This winding is connected in circuit with a battery and microphone.

The high-frequency current which is to be modulated is passed through windings X and Y on the two iron cores.

An instrument of this type has been employed successfully to modulate an energy output of 75 kw. at about 40,000 cycles.

Thermionic Valve Methods of Modulation.—Methods of modulation in which thermionic valves are employed are dealt with in Chapter XV.

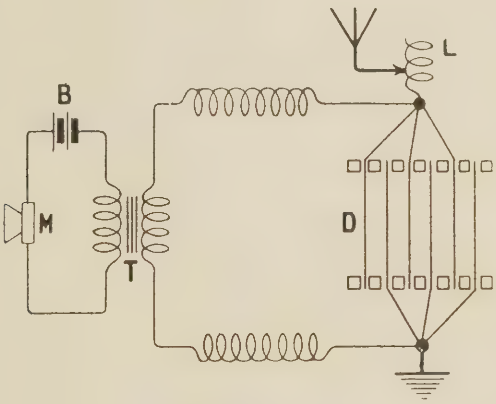


Fig. 116. The arrangement of Burstyn's Multiple Condenser Microphone

Coursey's Mercury Vapour Modulator (108).—This method of modulating large currents has been suggested by **P. R. Coursey.** Fig. 118 is a diagram taken from Coursey's book, "Telephony without Wires." The action is as follows: B is a battery of about 100 volts which supplies the current for the mercury vapour arc between a pool of mercury H forming the cathode and an anode A.

T and T_1 are two electrodes which are connected in the aerial circuit, carrying the current which it is desired to modulate. The tube X containing the mercury vapour arc is placed between the poles of an electro-magnet F, which deflects the arc stream in the direction of the electrodes B and C. The intensity of the magnetic field is controlled by means of a microphone M, through a transformer Q. When speech is being transmitted, owing to the varying displacement of the

arc stream in the varying magnetic field, the resistance between electrodes B and C is correspondingly varied.

The Marconi, Sykes-Round Microphone (as used by The British Broadcasting Co.)—Refs. (1020), (817), (910).*—This microphone was shown at the All-British Wireless Exhibition in 1923. In place of the usual diaphragm, this instrument is fitted with a spiral of fine wire, set in wax to stiffen it and form it into a flat disc having a circular hole at its centre A (Fig. 118A).

I is the core of an electro-magnet M, which projects just through the centre of coil A as shown. The latter is held in position against a light packing of cotton wool W by means

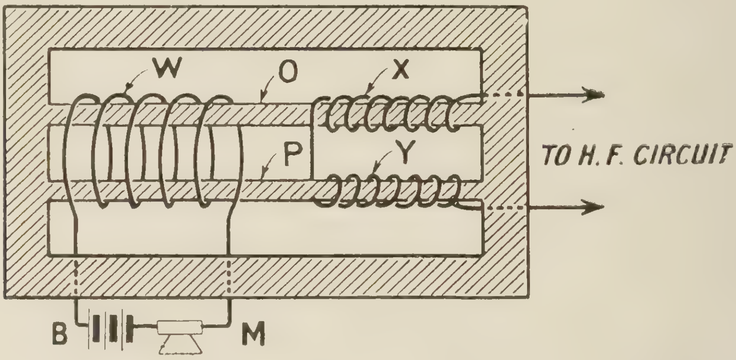


Fig. 117. Illustrates Alexanderson's scheme for modulating high-frequency currents.

of a little vaseline or other viscous material. The sound waves cause a slight movement of the coil in the field of the magnet, and by this means fluctuating electro-magnetic currents are generated in the coil.†

Tucker's Hot Wire Microphone.—‡In 1923, at his lecture to the Royal Society of Arts on "The Hot Wire Microphone and its Application to the Problems of Sound," **Major Tucker** (396) demonstrated the extraordinary sensitiveness of a hot wire to sounds when the wire was included in one arm of a Wheatstone bridge and placed at the orifice of a suitably constructed resonator (or sound-box). By tuning the resonator, the hot wire was only affected by certain notes.

This instrument was employed with great success during the Great War in locating the positions of the enemy's big

* See also Microphone of **Wagner** and **Lüschen**, Chapter II, page 23.

† Making use of the reverse of this principle, Round has constructed a loud-speaker, which was demonstrated at the N.A.R.M. Wireless Exhibition held at the Albert Hall, London, in September 1924. The reproduction was strikingly clear and free from predominant notes and distortion.

‡ See also Prof. Forbes, page 21.

guns, and would detect them through the din of rifle fire which entirely prevented them being heard by ear. The noise of the rifle fire could be rejected with ease, as it was causing sound waves of very much shorter length than those to which the resonator was attuned.

THE EMPLOYMENT OF THE HOT WIRE MICROPHONE IN WIRELESS RECEPTION (810).—As the available wavelengths in the ether become more and more employed in wireless transmissions it becomes more and more difficult to prevent jamming. The **author** has suggested (810) that when two or more stations are jamming one another to such an extent that it becomes a difficult problem to cut out the

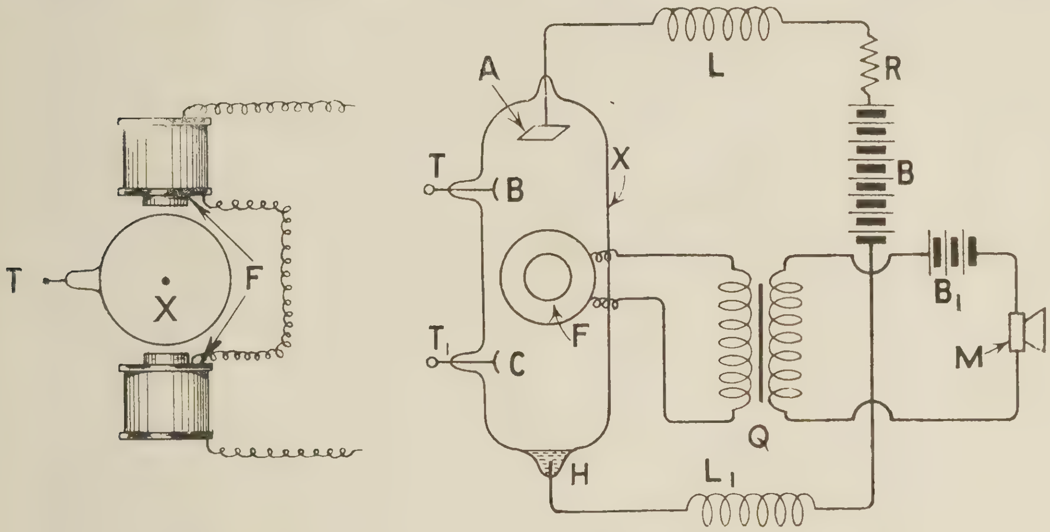


FIG. 118 (right). The circuit of Coursey's Mercury Vapour Modulator. The diagram on the left shows the disposition of the magnets F in relation to the arc tube X.

interfering station use might be made of the Hot Wire Microphone in procuring selectivity. The following is the suggested scheme :

M (Fig. 119) is the hot wire microphone included in one arm B of a Wheatstone bridge. X is a battery of sufficient voltage to keep the microphone (which consists of a spirally-wound filament of fine platinum wire) at red heat. The filament is placed in the orifice of a tubular resonator R, where any air movements into or out of the resonator are able to effect the resistance of the wire by their cooling action. H, H_1, and H_2 are holes in the side of the resonator cylinder, P is a plunger which allows the resonator to be tuned for the reception of a certain selected note. T and T_1 are leads connecting the Wheatstone bridge to a recording instrument. A is an ammeter indicating the current passing through the hot filament.

Suppose a telephone receiver Y be connected to the amplifier of a multi-valve receiving set, and that it is making the signals of two or more interfering stations loudly audible simultaneously. Provided that each station has a distinctive musical note, it should be possible to tune the resonator to the note of the station which we wish to record, and to reject the interfering stations. The hot wire microphone (an enlarged view of which is shown at M_1) is particularly sensitive to low-frequency disturbances.

KOEPSEL'S RELAY (881).—In 1907 **A. Koepsel** patented a relay which bears a strong resemblance to Tucker's hot wire microphone. The electrical connections are the same, *i.e.*

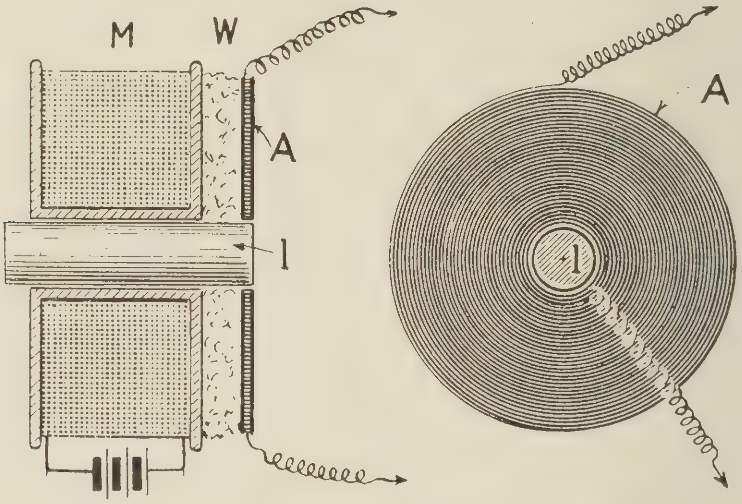


FIG. 118A. Illustrates the principle of the Marconi, Sykes-Round Microphone.

a hot wire forms one arm of a Wheatstone bridge. This wire is stretched between two supports, in front of, but not touching, one surface of a perforated mica disc, perforated in such a way that in one position a surface of mica is presented to the whole length of the hot wire. When the disc is very slightly rotated an air space (a hole in the disc) is presented to the entire length of the wire.

The necessary small rotary motion is applied to the disc electro-magnetically by the currents which it is desired to relay. The effect is to regulate the heat radiation from the wire, and so vary its resistance.

Increased sensitivity is obtained by allowing the movements of the disc to cover one arm of a "bridge," while uncovering the other.

The arrangement has been employed also for indicating the movements of a compass. When used as a relay the mica disc is carried by the moving system of a galvanometer.

Microphonic Telephonic Relays.—In his paper on microphones, before the Royal Society in 1878 (399), **Hughes** stated that if a telephone receiver included in a microphone circuit were placed upon a resonant board continuous sound could be produced. In the same lecture he predicted that the microphone might be employed as a relay for the human voice.

Lodge's 1898 Telegraphic Relay.—In 1898 **Sir Oliver Lodge** (406) invented a telegraphic relay consisting of several reeds or tuning forks, each carrying carbon contacts, and working in series. Each reed responded to one particular note, and when this note was passed through the relay its power was considerably amplified.

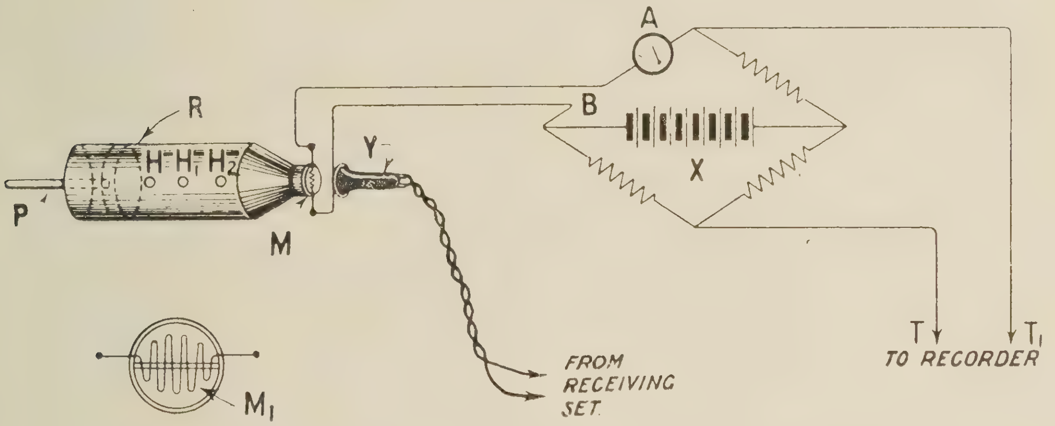


Fig. 119. A scheme suggested by the Author for making use of the properties of a hot wire microphone for selecting signals from one station when interference is experienced.

Fessenden's Differential Telephone Relay.—In 1906 (384), (50) **Fessenden** invented and successfully employed "differential" telephone relays.

Brown's Telephone Relay.—In 1910 **S. G. Brown** (407), (408) invented the now so well known Brown telephone relay. This is shown in Fig. 120 (A and B). P and P_1 are soft iron pole-pieces to a permanent magnet NS. The currents from the detector to be magnified pass round the upper windings of the pole-pieces as indicated. Just above the pole-pieces a fine reed R is free to vibrate. On the end of this reed is a tiny block of hard osmium-iridium alloy or other suitable metal, to act as contact for the fine point of an adjustable set screw S (also tipped with the same alloy).

A globule of oil is placed between the reed and set screw, which are connected in series with the secondary circuit windings M, M_1, and with a 1·5-volt battery B and an adjust-

able resistance V. C is a condenser to prevent the passage of continuous current through the phones T.

S. G. Brown has invented several other types of telephone relay embodying similar principles.

TUNED MICROPHONIC RELAY (92).—This is another type of relay employed by the German Wireless Telegraph Co. (409), and is tuned to the note it is desired to receive.*

FABIO MAJORANA'S RELAYS (92), (410).—In 1903 **Fabio Majorana** patented a microphone in which a microphonic contact was made between the fine fibre of a string galvanometer, in a powerful magnetic field, and a fixed contact.

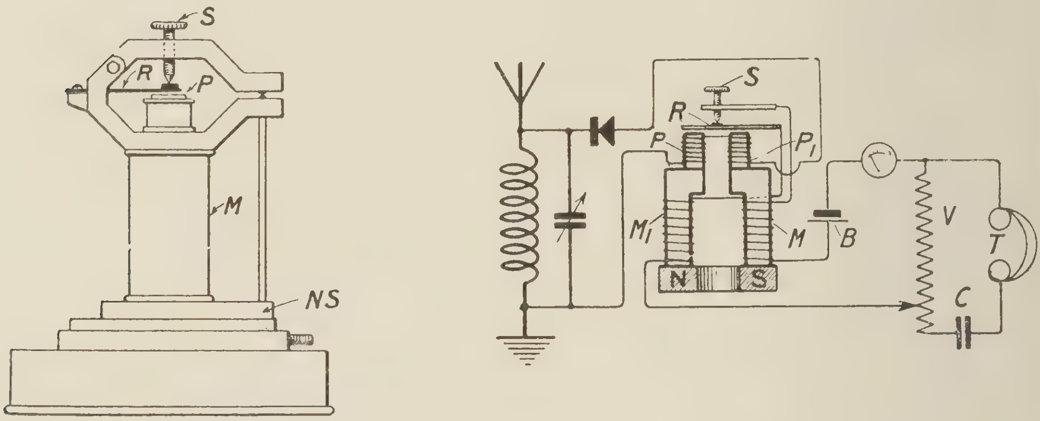


FIG. 120. Details of Brown's Telephone Relay. A shows the general arrangement and B the circuit diagram of the relay as used in conjunction with a crystal receiver.

In another form the movement of the fibre of a string galvanometer is made to control a liquid jet. (See also Orling jet relays, Chapter IX. pages 115 to 117).

THE FLAME AMPLIFIER.—The following Flame Amplifier was described by **Paul Horton,** in "Modern Electrics," in 1913 (347). The diagram shown in Fig. 121 is practically self-explanatory.

The currents from the detector pass round the windings B, and magnetize its iron core C. This causes vibration of two ferrotype diaphragms D and D_1, and corresponding variations in the gas pressure occur in the two chambers X and X_1, at either end of the bobbin, which in turn cause fluctuations of a gas flame G, increasing and decreasing the resistance of the space between two metal plates P and P_1, which are connected in

* An illustrated description of this instrument is given in **Dr. Eccles'** "Handbook of Formulæ and Data" (92).

series with a pair of 'phones T and a high-tension battery Z. The two gas chambers are connected by a tube S.

LEE DE FOREST'S MICROPHONIC FLAMES (219), (65).*—In 1923 **de Forest** described the following experiments: Two platinum electrodes were arranged a short distance apart in a "bat's wing" gas flame, rendered additionally conductive by the presence of potassium salts. A 200-volt battery and high-resistance 'phones were connected in series.

A gramophone, placed at a distance of three feet from the flame, could be clearly heard in the 'phones.

The reproduction was due to variations in the ionized

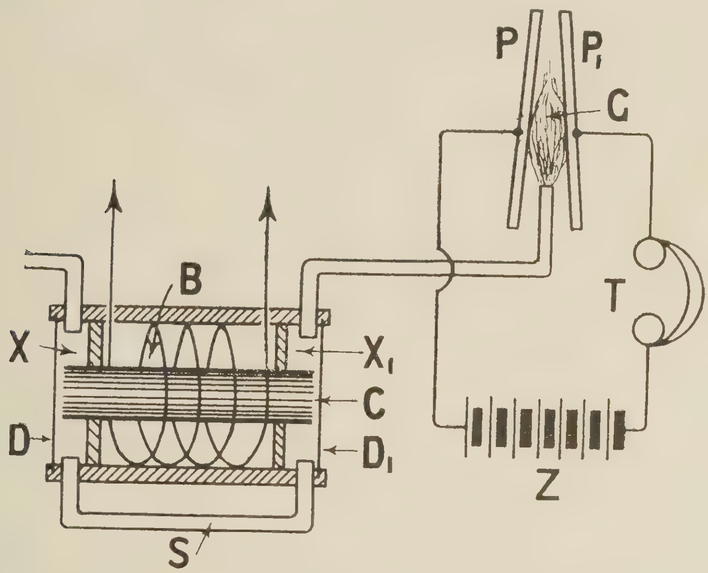


FIG. 121. Shows diagrammatically the arrangement of Horton's Flame Amplifier.

conductivity of the flame under the influence of the sound waves. He also experimented with Bunsen flames, with and without gas mantles therein; also with oxy-acetylene flames employing platinum electrodes encased in quartz, which becomes conductive in this flame. The latter arrangement gave remarkably clear reproduction of music.

* For other flame microphones see Chapter X. (**Blondel**, **Chambers**, and others).

Q

CHAPTER XIV.

The Work of R. A. Fessenden

Transmission of Photographs, Television, Radio-dynamic control, etc.

WE will now depart from the categorical description of apparatus with which we have been dealing and pass on to the great achievements of Fessenden in America. Those who have read the account of his lecture (384) delivered to the American I.E.E. in 1908 will appreciate the enormous amount of work he has done in connection with the development of radio-telephony. In 1903 he constructed a high-frequency alternator (385), (386), (387). He was the first to use a microphone in the aerial circuit. In 1906, by the employment of telephone relays of his own design, he demonstrated the possibility of connecting a land telephone line to a radio-telephone station. The following is an extract from his lecture previously referred to :

> " As it was realised that the use of wireless telephony would be seriously curtailed unless it could be operated in conjunction with wire lines, telephone relays were invented, both for receiving and transmitting ends, and were found to operate satisfactorily, speech being transmitted over line wire to the station at Brant Rock, and retransmitted there wirelessly by a telephone relay, received wirelessly at Plymouth, and there relayed on another wire line."

These tests were witnessed on December 11th, 1906, and reported in the " American Telephone Journal."

In 1907 Fessenden successfully transmitted speech between his station at Brant Rock and Jamaica (Long Island), a distance of 200 miles.

Fessenden's Interference Preventer should also be mentioned. This passed severe tests, and was said to be very satisfactory, by the American Navy Equipment Department in 1905. Finding that the waves used in wireless travelled more easily over ground having good electrical conductivity, Fessenden made use of a network of earth wires, which he termed a " wave chute." He was the first to erect an aerial consisting of a steel tube on an insulating foundation held in position by insulated stays.

In 1902 (92) he proposed the method of " Heterodyne " beat reception, but it was not brought into a state of complete development until 1907 (see also Chapter VI. : " Fessenden's Heterodyne Receiver ").

PHOTOGRAPHIC METHOD.*—In 1914 **A. A. Campbell Swinton,** in his Presidential Address to the London Wireless Society, described a method of receiving messages on a moving strip of sensitized paper which photographed the movement of a sensitive manometric flame actuated by the sound of signals from a telephone receiver. He exhibited several messages, which he recorded in that manner, and also records made by aid of a mirror galvanometer.

He also demonstrated the use of a "siphon" recorder and described Poulsen's method of recording signals by means of an "Einthoven" string galvanometer.

A congratulatory message was received and recorded on this occasion from General Ferrié from the Eiffel Tower.

Six years later, again on the occasion of his Presidential Address to the London Wireless Society, he received congratulatory messages from the Eiffel Tower, but on this occasion, by the employment of valves, he was able to receive the messages on a frame aerial standing on the lecture table.†

THE "DICTAPHONE" (OR PHONOGRAPH) EMPLOYED TO RECORD MORSE SIGNALS.—This method, patented by Fessenden in 1907 (879), is satisfactorily employed for the reception and recording of Morse signals. It is capable of taking down the fastest automatic transmissions, which arrive at a speed too great to be read by ear. All one has to do in order to read them afterwards is to place the wax cylinder on the "Dictaphone" reproducer, and by altering the speed at which it revolves signals can be reproduced as slowly as desired.

W. Scott, of the London Telegraph Training College, was one of the first to employ this method in England, making records of Morse signals which he reproduced at any desired speed for instructional purposes.

RECORDING TELEPHONY ON A "DICTAPHONE."—On October 17th, 1922, the **Author** carried out an experiment, in conjunction with **Captain H. S. Walker,** in which use was made of this method of recording speech. Captain Walker transmitted by wireless from Brentford a song by Caruso from a

* For description of **D. McNamara's** photographic recorder see Ref. (558). See also Radium Recording Devices (826) and (827).

† It is interesting to note that the London Wireless Society came into being as the London Wireless Club in 1913. The name was changed to the Wireless Society of London when Mr. Campbell Swinton gave the First Presidential Address, in 1914, and the name was again changed during the Presidency of Admiral Sir Henry Jackson, in 1922, to the Radio Society of Great Britain (790).

gramophone record. The Author received this at Richmond, and recorded the whole song on the wax cylinder of a "Dictaphone." The record was then placed in a phonograph, and the song was retransmitted wirelessly to Brentford. The chief interest in the experiment was the wonder it engendered when one remembered that Caruso had been dead for more than a year, and yet we were, so to speak, juggling with his actual voice.

This method of recording the signals is extremely simple. Having amplified up the received speech or music to a fairly loud strength, the horns are removed from the loud speaker and from the "Dictaphone," and the telephone belonging to the former is placed over the tone arm of the "Dictaphone" in place of its horn, and a record is then made.

THE PHOTOGRAPHOPHONE.—The photographophone described in Chapter X. (page 143) could also be employed for recording signals or speech.

VALDEMAR POULSEN'S TELEGRAPHONE, OR MAGNETIC SPEECH RECORDER (785), (388), (389), (395), (784).—At the Paris Universal Exhibition of 1900 the Telegraphone invented by **Valdemar Poulsen,** of Copenhagen, attracted much attention, both on account of its simplicity and regularity of working. The apparatus, in its earliest form, consisted of a steel wire or ribbon, which was passed between the poles of an electro-magnet connected in series with a telephone circuit. As the wire was drawn slowly through the field of the magnet it received therefrom a series of transverse magnetizations corresponding to the sounds received, and, in a sense, a magnetic curve of speech was fixed upon the ribbon, which afterwards, by a reversal of the process (*i.e.* by passing the steel wire or ribbon thus magnetized between the poles of a magnet connected in series with a telephone receiver), enabled the speech to be reproduced.

PEDERSEN'S SIMULTANEOUS RECORDING AND REPRODUCING.—In 1902 **Pedersen** succeeded in taking down two 'phone messages simultaneously on one steel wire, and afterwards reproducing them simultaneously and in two separate receivers without interference of one with the other.

POULSEN'S IMPROVED TELEGRAPHONES.—In 1906 **Poulsen** (395) improved the design of the apparatus.* The steel wire was wound tightly round a cylinder, which, by a clock-

* For another form of telegraphone in which interchangeable discs are employed in place of steel wire see Ref. (784).

work mechanism, was caused to revolve in a vertical position, in a similar manner to a phonograph record. When recording speech the poles of an electro-magnet similar to that employed in a telephone receiver (and which was free to slide up and down a polished rod arranged parallel to the cylinder), was pressed steadily against the wire on the cylinder at one point. As the cylinder revolved, the electro-magnet travelled along the wire from end to end of the cylinder, in a similar manner to the movement of the stylus of a phonographic reproducer along its wax cylinder. To reproduce speech from the steel wire, the magnet was disconnected from the receiving instrument, and, having been connected in series with a telephone receiver, was brought back to its first position, and again caused to travel the length of the cylinder.

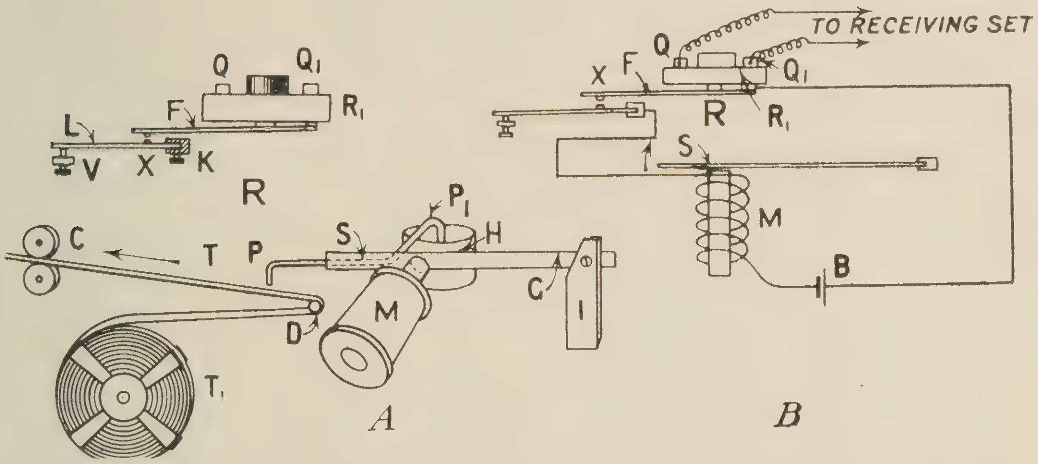


FIG. 122. A shows the essential arrangements of Winkler's Siphon Recorder; B indicates the electrical connections; and R the construction of the relay.

WINKLER'S SIPHON RECORDER (550), (811).—A most effective siphon recorder was invented (in 1922) by **Winkler.** It is so simple in design that an effective working model was made by a boy of 15 years of age and exhibited at the All-British Wireless Exhibition at the White City, in Nov. 1923, amongst the exhibits of the Radio Society of Great Britain, "Schools" Section.

Fig. 122A shows the general scheme of this recorder. The tape T is unwound from its reel T_1 by a clockwork drive C, which keeps it tightly stretched over a polished steel rod or roller D. P is a silver "siphon" tube, attached to a steel spring G, with one end resting vertically on the tape and the other end (P_1) dipping into an ink-well H.

When no signals are being recorded the electric-magnet M holds the spring against its pole (it is prevented from adhering thereto by the interposition of a sheet of paper). R is the relay, which consists of a " Brown " 'phone (A type) having an extension arm F fitted to its reed. This reed extension makes contact with a delicately adjustable contact X.

Fig. 122B shows the electrical connections. When the reed F of the telephone vibrates in response to signals, a variation of resistance takes place between the contacts X, resulting in movements of the spring S, and movements of the syphon tube across the tape to a greater or lesser extent, in this way the signals are recorded.

This recorder, if delicately adjusted, will record without difficulty from a 2-valve set.*

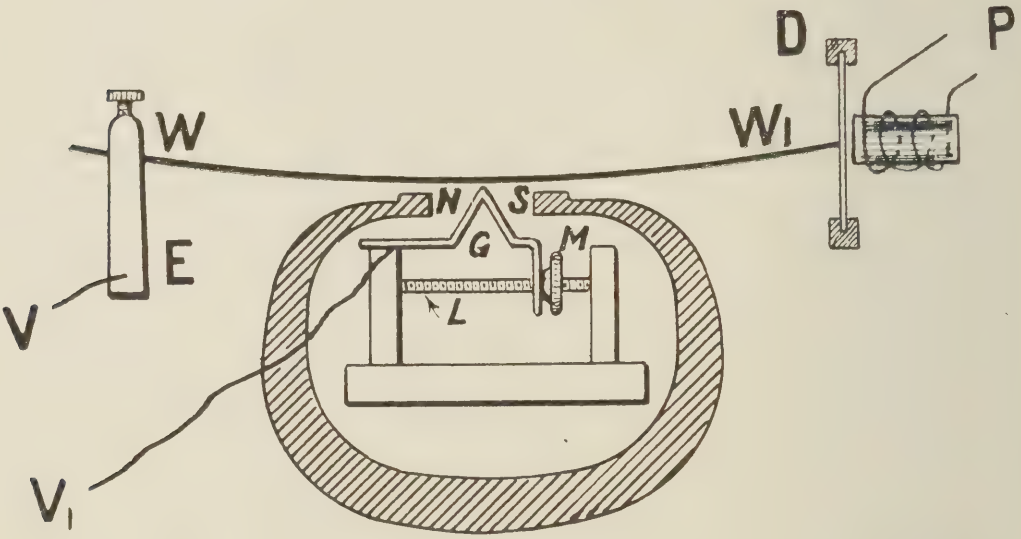


FIG. 123. Bront's Mechanical Relay depends for its working on the variations of resistance of the contact between the steel wire WW_1 and the spring G.

BRONT'S MECHANICAL RELAY.—Fig. 123 shows a sensitive relay somewhat similar to that employed by Winkler for " siphon " recording. WW_1 is a steel wire suspended between a solid fixing E and the diaphragm of a telephone D. It is bowed downwards very slightly at its centre, and held in position by the attraction of magnet NS.

The local circuit comprising the " siphon " recorder, and a small battery, is connected at V to the steel wire WW_1, and at V_1 to a delicately adjustable spring G with which the wire makes light contact.

* Another simple method of constructing a siphon recorder is described by **Winkler** in Ref. (823).

M is a micrometer screw which travels along the threaded rod L; when it is screwed round, it presses the spring G slightly upwards.

RADIUM RECORDING DEVICES.—**J. H. Powell** described a very ingenious type of recorder in the "Journal of Scientific Instruments" in 1924 (826), (827).

In place of a recording pen, a small speck of radium is employed. The rays from this fall upon photographic paper, on a revolving drum. This arrangement obviates the necessity for the pen to be in actual contact with the paper, and so avoids friction. The revolving drum need not be in the dark, as

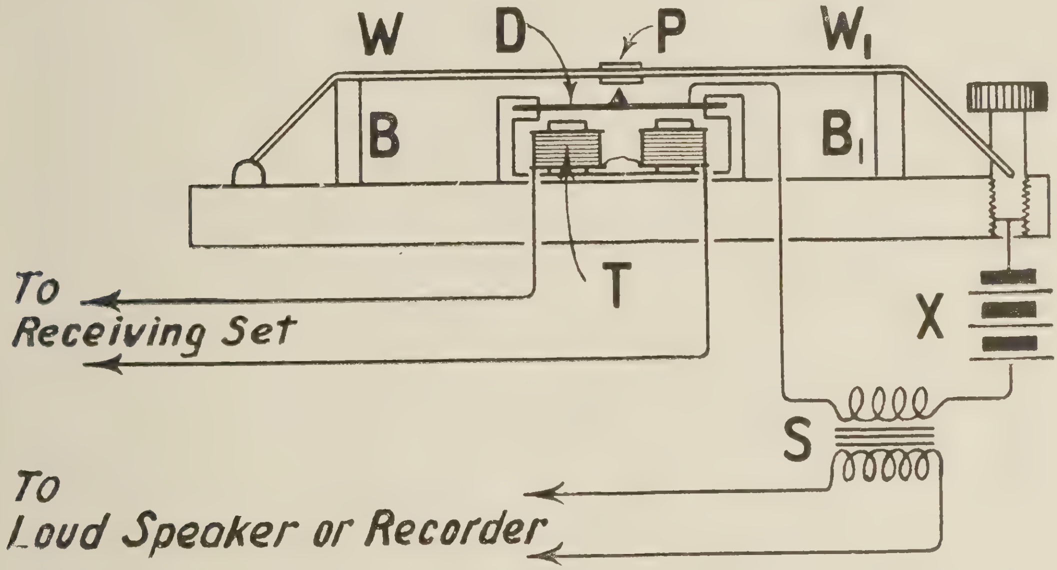


FIG. 123A. A simple form of relay employing an ordinary high-resistance telephone earpiece.

the radium rays easily penetrate a layer of black paper with which it is covered in order to protect it from light until it has been developed.

ANOTHER SIMPLE MICROPHONIC RELAY (754).—Fig. 123A illustrates another very simple type of microphonic relay. A taut wire WW_1 is stretched over the diaphragm of an ordinary high-resistance 'phone T. A platinum contact sleeve is attached to the centre of the wire, which rests lightly against a platinum point attached to the centre of the telephone diaphragm D. This contact closes the local circuit of a battery X, through the primary of a transformer S the secondary of which is connected to a loud speaker, or to recording instruments.

K. C. COX'S SELENIUM AMPLIFIER (1028).—This instrument was exhibited at the Physical Society's Exhibition at

South Kensington on January 23rd, 1921. By its aid it is claimed that an amplification of 40,000 may be obtained. Fig. 124 shows the general scheme of the apparatus.

The signal currents which it is desired to amplify are passed through the moving coil of a mirror galvanometer G, which reflects a beam of light from a lamp X on to two selenium cells S and S_1. By means of a grid L it is arranged that when the galvanometer is at zero one half or each cell is illuminated and the other half is in the shade, so as to balance the Wheatstone bridge of which they form two variable arms. Galvanometer deflections cause the image of the grid to move across

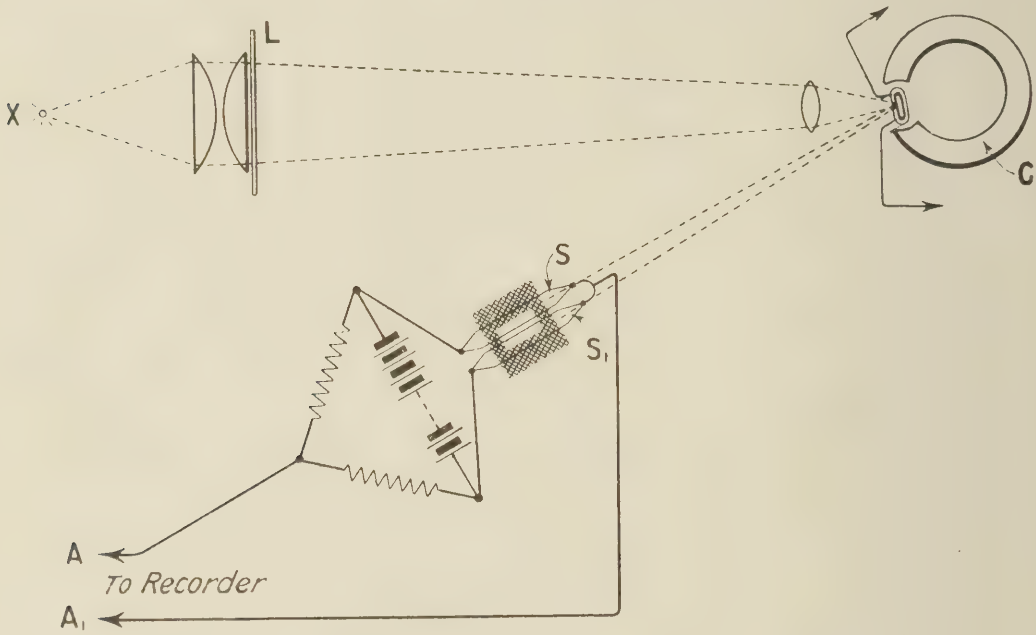


FIG. 124. Shows the arrangement of Cox's Selenium Cell Amplifier.

the cells, so that the dark part now becomes illuminated, and vice versa.

A recorder or relay is connected across the bridge by means of the leads A and A_1, shown in Fig. 124.

The selenium cells are of special construction, each complete cell being made up of 24 pairs, and one bar or line of light from the grid is shared by each individual pair, in order to make as much use as possible of the smallest deflection.

The " inertia " of the selenium is reduced by shunting the recording apparatus with a suitable inductance.

OTHER METHODS OF RECORDING.*—The reader is referred to the discussion " On Some Methods of Recording Wireless

* Reference should also be made to the mercury jet relays described in Chapter IX. of this book. See also **G. G. Blake's** employment of the "Zero Shunt" method for recording, Chapter XVI.

Signals" held by the Wireless Society of London on Sept. 30th, 1921 (557). At this meeting, amongst other methods, the following were discussed: E. W. F. Alexanderson's Wheatstone bridge method, the methods of Johnsen and Rahbek, Poulsen and Pedersen, A. A. Campbell Swinton, Creed, Burbury, H. Haynes, Carpenter, Klein, Shortt, Reeves, Boyer, Turner, the Hall relay, etc.

F. G. Creed's Method of Automatic Transmission, Reception, and Reproduction in Roman Type.—There are various other methods of recording signals, including the **Creed** method of automatic transmission and reception.

In 1920 **A. A. Campbell Swinton**, in his opening address as Chairman of the Royal Society of Arts (390), gave the first public demonstration of the printing of wireless messages directly in roman type by means of **F. G. Creed's** printer and receiver, and in that lecture he gave a description of the Creed system and received signals from the Admiralty at Hornsea, near Portsmouth.

These signals were transmitted automatically from Hornsea at a high speed from a punched tape. When the receiving set was properly tuned the signals were passed through the Creed apparatus, which automatically punched out the dots and dashes on a tape, and produced an exact facsimile to the tape employed at the sending station. The tape was then run through another piece of Creed apparatus, which automatically transcribed the Morse into roman letters and printed them on a tape. A message was also specially sent out from the Eiffel Tower from General Ferrié, and received and reprinted in the same way by the Creed machine.*

The Lodge-Muirhead Automatic Transmitter.—One of the earliest automatic wireless transmitters was probably that employed during the early days of spark transmission at Elmers End by the Lodge-Muirhead Co. These transmissions were, however, at a very slow speed.

Westhead Automatic Transmitter.—On January 10th, 1909 (397), the "Daily News" commenced transmitting the news from their London newspaper, using a Westhead automatic telegraphic transmitter, which enabled them to transmit messages over land lines at a speed of over 200 words per minute, so that they were, by its aid, enabled to reprint the paper in Manchester in time for practically

* For description of the high-speed apparatus of **Hughes, Creed,** and **Baudot** see Ref. (779).

simultaneous publication with their London edition. The MS. was first typed out on to a strip on a Gell perforator.

P. O. PEDERSEN'S AUTOMATIC TRANSMITTER (391), (392), (393).—In 1911 **Pedersen** succeeded in transmitting Morse signals at 300 words per minute, by means of an automatic transmitter and recorder, between Lyngby (near Copenhagen) and Knockroe (1500 km.).

(See also recent applications of Hughes' type printing telegraph already described in Chapter III.)

DUPLEX AND MULTIPLEX RADIO-TELEGRAPHY AND TELEPHONY (965–975), (172–180), (1043), (1044), (1051), (1052).—A great many methods have been devised to solve the problem of simultaneous transmission and reception between two stations.

FESSENDEN.—**Fessenden** suggested a method in 1908.

MARCONI.—**Marconi** suggested the use of a disc discharger in this connection, the idea being to receive during the idle intervals between the discharge studs.

For transatlantic work the **Marconi Company** employ on each side of the Atlantic, two separate stations some miles apart and connected by a land line. The operators are at the receiving station and are able to transmit by using a distant-control system working over the land lines connecting the two stations. The transmitting stations employ different wavelengths, so that simultaneous transmission and reception across the Atlantic are possible.

EISENSTEIN.—**Eisenstein** pointed out, in 1908, that in order to avoid interference with reception during transmission the wavelength employed for the latter must be widely different from that on which signals are being received, and that the transmitting aerial should be much higher than that employed for reception.

ECCLES.—In 1909 **Eccles** suggested the use of directive aerials for duplex working.

MARCONI CO.—The **Marconi Co.** has also a system in which a balancing aerial is employed (92).

POULSEN.—As far back as 1906 **Poulsen** succeeded in carrying on duplex radio-telegraphy on C.W.

Much work has been carried out by the G.P.O. in this direction, using short wavelengths.

THE MARCONI CO. (DUPLEX EXPERIMENTS OF 1921) (549).—The **Marconi Co.** conducted some successful duplex

wireless telephony across the North Sea in 1921: from Southwold, on the East Coast, to Landvoort, near Haarlem, in Holland (112 miles).

THE RADIO CORPORATION OF AMERICA (681).—The **Radio Corporation** works a high-speed transatlantic duplex wireless service between their stations at Marion and Chatham (Mass.) and stations at Stavanger and Naerobe in Norway.

OTHER DUPLEX AND MULTIPLEX SYSTEMS.—There are many other systems, including those of: Lloyd Espenschied (456), Englund (456), De Forest (546 to 548), A. N. Goldsmith and J. Weinberger (794), Fessenden (880), and many others. See also References (542), (634), (661), (768), (965 to 975).

TIME SIGNALS

TIME SIGNALS (595), (596), (597).—**Tesla** and many others, since the earliest days of wireless, had suggested the employment of wireless as a means of correct timekeeping.

In 1902 **General Ferrié** installed a receiving apparatus at the top of the Eiffel Tower,* using a comparatively short aerial, and the framework of the tower itself as an earth. In the same year he installed a small station in a wooden hut on the Champs de Mars, connected to an aerial suspended from the top of the tower. The first experiments for transmission of time from the Eiffel Tower were made by General Ferrié in 1909, and a regular service was announced in 1910. (The valve transmitting set was first experimented with at the Eiffel Tower in 1921 (679).)

This was, I believe, the first powerful station to give a regular transmission of time signals. An American Naval station also transmitted time signals in 1909. Before the War a German radio station, "Norddeutsch," commenced a series of time signals in 1911. During the War, in 1919, "Nauen" (799) also began a time signal service.

RADIOTELEINSCRIPTION.—This is a method for the radio-transmission of writing or drawings, the "Wireless" equivalent of the well-known telewriter, used on land telephone lines for the telegraphic transmission of handwriting or drawings.

Several more or less satisfactory devices have been suggested for this purpose (554).

* For photographs and diagrams of the time-signalling apparatus employed at the Eiffel Tower see Ref. (664).

Wireless Transmission of Photographs, or Telephotography

The "Pantelegraph"* of Bonelli and Caselli.—In "Natural Philosophy," by Privat Deschanel, translated by J. D. Everett in 1872 (3), a full description, with illustrations, is given of an autographic telegraph, invented by **Bonelli** and **Caselli**, and called the "Pantelegraph." A very satisfactory specimen picture before and after transmission is shown.

It states that this instrument was employed also to copy letters, and, when the book was written, had been employed for some years on the telegraphs around Havre and Lyons; but adds: "It has not realized the hopes of its promoters, its dispatches being often illegible."

One of these instruments was exhibited at the Paris Exhibition of 1900 (610).

Belin's System of Telephotography.—In 1904 **Edouard Belin** (609), (792)† took out his first patent for the transmission of photographs by wires, and, later, he so perfected his system of telephotography that it has been adopted by the French Postal and Telegraph Authorities, and stations have been erected in Paris, Lyons, and Strasburg. Photographs of persons, views, finger prints, Chinese and Japanese writing, and even shorthand, are transmitted and faithfully reproduced over long distances by this system.

It has also been applied to Wireless, and radio-telegraphic transmission has been successfully achieved.

Korn's Photographic Transmission Method.—In 1905 **Professor Korn**, of Munich University (680), (555), (579), employed arc transmission, and recorded, by means of an Einthoven string galvanometer and other apparatus.

Knudsen's Method.—In 1908 (555) **Hans Knudsen** transmitted pictures by means of spark transmissions and coherer reception.

Thorne Baker (1085).—In 1908, also, **Thorne Baker**, in England, transmitted hundreds of pictures over telephone lines, and, later, satisfactorily transmitted pictures wirelessly.

Waltz and Meusser's Method (1053).—In 1919 **E. Waltz** and **H. Meusser** patented a thermionic valve method for recording and reproducing sounds and picture reliefs.

* See also the work of **Ayrton** and **Perry**. Also of **Shelford Bidwell** (Ref. 771).

† See account of Edouard Belin's lecture before the Society of Arts on Nov. 13th, 1923.

Thorwald Andersen.—In 1920 **Thorwald Andersen** (682), a Danish watchmaker, invented a satisfactory system, which was taken up by the Danish Government Telegraph Department, and a picture of a young woman was transmitted wirelessly from the wireless station at Bloavondshuk to Lingby, near Copenhagen. (The transmission took the same time as the ordinary telegraphic transmission of 100 words.)

During the same year Andersen transmitted some excellent photographs by radio from Denmark across the North Sea to London.

American " Pictographic " Transmissions (1056), (1066).—In America, the American Telephone and Telegraph Co. and the Western Electric Co. have carried out much research work on the transmission of pictures by wire and wireless. An account of the successful transmission of a "pictogram" of President Coolidge by the A.T. & T. Co. from Cleveland to New York, over 520 miles of a long-distance telephone line, was given in the New York "Tribune" in May, 1924.

Radio-transmission of Pictures from England to America.—On November 30th, 1924, the **Marconi Company,** in collaboration with the Radio Corporation of America, successfully transmitted photographs of the Prince of Wales, President Coolidge, and Mr. Charles E. Hughes (the American Secretary of State).

The pictures were reproduced, after reception, in the " New York Times," and in the " Daily Telegraph," of December 16th, 1924.

N. Maskelyne's Method of Reproducing Pictures by Code (1033).—In 1908 **Maskelyne** patented a method of reproducing drawings, etc., at a distance. The following is an abstract from his patent :

> "A photographic enlargement is first made of the picture. A transparent tissue sheet is then laid over it, the latter being divided into small squares by vertical and horizontal lines. The relative density of these squares is estimated by the eye against a standard scale of six tints, and information of these densities is transmitted to the distant station by telephone, telegraph, wireless telegraphy, sound signals, flag signals, or by post."

"At the receiving station the picture is reconstructed by means of type adapted to give impressions corresponding to the six standard tints, and the impression from the reconstructed block is then photographically reduced."

A photograph of His Majesty King George V. was "dictated" by a very similar method from the London station of the British Broadcasting Company, on May 24th, 1923, by Fournier d'Albe (1034).

Television (556), (1056), (1061), (1058), (1059), (1060), (1062).—On March 26th, 1924, **A. A. Campbell Swinton** gave a very comprehensive paper on the possibility of Television before the Radio Society of Great Britain (1061). In this paper he speaks of an instrument designed by **Carley,** and described in an old scientific periodical (now out of print), "Design and Work," of June 26th, 1880, as being probably one of the earliest attempts at seeing by wire. In his paper, after reference to the work of **Korn, Belin, Thorne, Baker, Shelford, Bidwell** (1058), **Fournier d'Albe,** and **Nicholas Langer** (556), he refers to his original suggestion in a letter which he wrote to "Nature" in 1908 (1059), in which he was the first to suggest the employment of two cathode beams, one at the transmitting station and one at the receiving station, synchronously deflected by the varying electro-magnetic fields of electro-magnets placed at right angles to one another, and controlled by alternating currents of differing frequency.

The movements of the cathode stream could be made so rapidly by this means that a small ray could be made to cover the entire area of a fluorescent screen, during persistence of vision, so that the whole surface would have the appearance of being illuminated simultaneously.

In his Presidential Address before the Röntgen Society, in 1911, he amplified this idea, and gave a diagram showing how such a system might possibly be worked. At the transmitting end the screen is composed of a number of small cubes of rubidium (which is highly photo-electric, *i.e.* freely emits electrons when acted upon by light). The scene or picture to be transmitted is focussed upon a small gauze screen placed between the rubidium cubes and the lens, but not quite touching the former, the space between being filled with sodium vapour. The different cubes would now be each illuminated to a different degree by the image focussed upon them, consequently the sodium vapour is ionized to a different

extent in the vicinity of each cube. On its way to the reverse side of the cubes the cathode stream passes through an aperture in a metal plate connected to earth. The transmitting circuit is completed by a line wire leading from the gauze screen to a plate on one side of the path of the cathode stream in the receiving oscilloscope. As the ray travels, say, horizontally across the rubidium cubes at the transmitter the voltage of the gauze screen keeps varying in accordance with the amount of ionization at each cube, due to the light in that portion of the picture or scene focussed upon it, and the varying voltages are applied to the before-mentioned metal plate in the receiving oscilloscope and create an electro-static field which deflects the cathode stream in exact accordance with these voltage variations. The cathode stream in the receiving instruments impinges upon a fluorescent screen at the end of the oscilloscope. The vertical movements of both cathode streams are made by means of the electro-magnetic field of two electro-magnets, connected in series with a common A.C. supply, by means of two additional lines joining the transmitting and receiving instruments. These magnets are so placed against the outsides of their respective oscilloscope tubes that they cause the cathode stream therein to oscillate at right angles to their other movements. In his 1924 paper to the R.S.G.B., Swinton gives further diagrams and suggestions for the adaptation of this idea to radio-television.

The Experiments of Nicholas Langer (556).—**Nicholas Langer,** in Hungary, has experimented in television, employing tiny oscillating mirrors in magnetic fields controlling currents through selenium cells. The method is extremely complicated, and, as it is rather outside the scope of this book, the interested reader is referred to Reference (556), wherein a full and detailed description will be found.

J. L. Baird's Experiments in Wireless Television (1056).—In Scotland, **Baird** has conducted some experiments on the following lines: A hole was cut in a sheet of cardboard, in the shape of a cross, and brilliant light was placed on one side of the cardboard sheet and the cross-shaped ray was focussed by a lens on to a selenium cell. Between the cell and the lens is placed a rapidly-revolving perforated disc, the holes in the latter being punched in a series of fives. The first hole is on the edge of the disc, the second a little

nearer the centre, the third nearer still, and so on to the fifth hole, which is quite near to the centre.

The revolving disc in front of the beam splits up the image into a series of flashes following each other at a speed so great that the eye is deceived and the whole of the cross appears to be sent at once. In front of this disc is another, revolving in the opposite direction. On its circumference a number of spokes are so arranged that they cut across the flashes of light passed through by the perforations in the first disc. The total effect of this is to pass through flashes of light, each of which is broken up by a series of interruptions having a frequency equivalent to that of a high-pitched musical note. Under these conditions the image is now focussed on to a selenium or other light-sensitive cell. If a telephone is connected in circuit with the latter a shrill sound will be heard, which is the " sound equivalent " of the picture being transmitted.

Instead of connecting the cell to a telephone receiver, it is in practice connected to an amplifier, and from thence it is employed to modulate the carrier wave from a C.W. transmitting station. At the receiving station, after suitable amplification of the received impulses, they are passed to an apparatus designed to make them visible to the eye. This consists of a disc, upon which there are a number of quick-acting electric lamps arranged in positions corresponding exactly with the perforations in the transmitting disc. Each of these lamps is connected to a commutator to which the received impulses are being fed.

The disc at the receiving station is revolved at the same speed as the transmitting disc, and the lamps light up in sympathy with the flashes of light at the transmitting station and form the original image of the cross or other object transmitted.

Radio Control of Mechanisms

Branly's Early Experiments (745).—**Branly** was probably the first to demonstrate the possibility of performing operations at a distance by means of apparatus controlled by Hertzian waves. He constructed apparatus very shortly after his invention of the " Branly Coherer," in which the latter was connected to a relay, which closed various local circuits through a clockwork distributor. By means of this apparatus, operated from a distant spark transmitter, he was

able to light an electric lamp, start a small motor, and control other instruments.

A considerable amount of work has been done in this direction since then. Many ingenious schemes have been evolved for the distant control by Hertzian waves of aircraft, motor-cars, torpedo-boats, etc. (See Refs. (398), (592), (593), (468), (483), (586), (587), (635 to 642), (745), (746), (898), (899), (900), (921–931), (1044), (1045).)

TORPEDO BOAT.—H. DEVAUX'S METHOD OF WIRELESS CONTROL.—In 1906 **Devaux** (398) described, in a paper which he delivered before La Société Internationale des Electriciens, a method of controlling a submarine torpedo-boat by means of Hertzian waves.

The receiver consisted of a coherer connected to aerial and earth. The waves received from the transmitting station operated a relay, which closed a local circuit, through a powerful electro-magnet. Above the poles of the latter a lever arm was pivoted, carrying on one end a pawl engaging in a ratchet-wheel. Each wave train received, (from a sudden depression and release of the key at the transmitting station), caused the ratchet wheel to move round one tooth forward. In so doing it moved a contact arm from stud to stud and switched on or off various control circuits. A damping device was arranged at the other end of the lever arm, to ensure that the contact arm had to dwell for an appreciable time upon any stud before the circuit was completed and the control came into operation. If a rapid succession of transmitted impulses were received the contact arm moved rapidly on from stud to stud, and only when the transmitting station ceased sending, and the contact arm had remained for an appreciable time on the stud with which it was making contact, did the control come into operation.

R. MARTIN'S TORPEDO CONTROL METHOD (592).—In 1916 **R. Martin** patented in France a method of torpedo control from an aeroplane.

AIRSHIP (WIRELESS CONTROL OF) (468).—In 1911 **Raymond Phillip** exhibited a small model airship at the London Hippodrome and Coliseum. A description of the scheme which he employed is given in Reference (468), and is very similar to that employed by Devaux for the control of his torpedo.

Ships (Radio Control of) (183).—In 1918 **Dolme-Dehan** and **Abraham,** and also **Chauveau,** carried out some useful investigations in the radio control of ships, and experiments in this direction were carried out by the Committee of Researches and Inventions on the Seine, near Paris.

Radio Control in Warfare (593).—In 1917 **G. de Trarrazaval** patented a method of controlling engines for use in warfare provided with explosives.

In 1918 the Engineers of the French Signal Corps, under the direction of **General Ferrié,** constructed an aeroplane, controlled by wireless, which would carry explosives over the enemy's lines and drop them when released by radio at the proper instant, or it could be used to take photographs.

Tests were made with the machine, on September 14th, 1918, when it flew successfully, without a pilot, over the aerodrome of Chicheny, for 51 minutes, executing various complicated manœuvres, and covering in all a distance of 80 miles.

French Government Tests.—In 1921 **Max Boucher** and **Maurice Percheron** (745) and (483) studied this problem with a view to the possible development of radio-controlled aircraft for use in peace time.

An aerodynamic rudder invented by **Doutre,** and **Sperry** gyroscopic stabilizers, were employed to enable the aeroplane to keep in its position of equilibrium.

Experiments carried out at Etampes were most satisfactory, and proved the possibility of automatic flying. The aeroplane, thus equipped, remains automatically in a position of equilibrium, and all the pilot needs to do is to guide it on its course, as a captain steers his ship. For short distance flights the pilot can be dispensed with. For the transportation of cargo or for the purpose of making meteorological observations, the machine can be controlled by wireless.

On June 28th, 1923, severe tests were passed by the radio-controlled aeroplane before the Reception Committee of the Aeronautical Technical Service of the French Government, consisting of 15-minute flights at various altitudes. In the last of these the aeroplane had to effect a spiral landing of 1,000 feet in diameter, from a height of 3,000 feet, which it accomplished perfectly.

The following quotation, from Reference (745), is interesting as showing the probable future of wireless control : " These

tests show that the automatic radio-controlled aeroplane is practical, and may be developed to such a degree of perfection that it will be possible in the very near future to use it for commercial purposes by sending it up, directing it towards a city, and taking it down again by means of another radio station installed on the landing field, which would take over the control of the plane upon its arrival within the radius of the controlling station, the plane flying by itself between two aerodromes."

MOTOR-CAR CONTROLLED BY WIRELESS (746).—In America, **F. W. Dunmore,** of the United States Bureau of Standards, described (in the "American I.E.E. Journal") a method of radio-control employing valve circuits (the description of a small car controlled by this method is given in Reference (746)).

WEBB'S METHOD OF RADIO CONTROL (754).—In 1923 **H. W. Webb,** at the Ohio University, devised a system of radio-control in which tuning forks were employed :

(*a*) To control or modulate a carrier wave at the transmitting station.

(*b*) To vibrate in response to the received impulses after the latter have been amplified at the receiving station.

(*c*) To quench the vibration of the first fork, a second fork being suitably arranged at the receiving station; this rapidly quenched the vibration of the former, directly it had closed the contact of a relay circuit, thus overcoming the difficulty due to prolonged vibration of the fork after it had performed its work.

By means of this apparatus he was able to ring a bell, light a small lamp, etc. The principle is similar to the **Johnson Guyott** system described in Chapter IX., but far more practical, as it employs Hertzian waves.

RADIO CONTROL OF MASSIVE MACHINERY (1035).—On September 3rd, 1924, the Metropolitan-Vickers Company carried out a test in distant (170 miles) radio control of power plant.

From their transmitting station at Trafford Park, Manchester, they succeeded first in starting up, and later in stopping, a 500-kilowatt rotary converter (of the type employed for town electricity supply) installed in the Palace of Engineering at the British Empire Exhibition at Wembley.

This achievement opens up many commercial possibilities.

WIRELESS ON SUBMARINES (587), (638).—In a most interesting article (Reference 587), **P. R. Coursey** describes the employment of wireless on submarines. He gives the transmitting range of a submarine (using an aerial current of 12 amperes) as 50 miles, when running at full speed on the surface. This is reduced to 12 miles if the aerial (which is, of course, well insulated) is only just submerged. At a depth of nine feet he gives three miles as the outside limit of range.

RADIO-TELEPHONIC COMMUNICATION BETWEEN AEROPLANES IN FLIGHT AND LAND STATIONS (586).—Great use of wireless telephony is now made in directing aeroplanes and giving

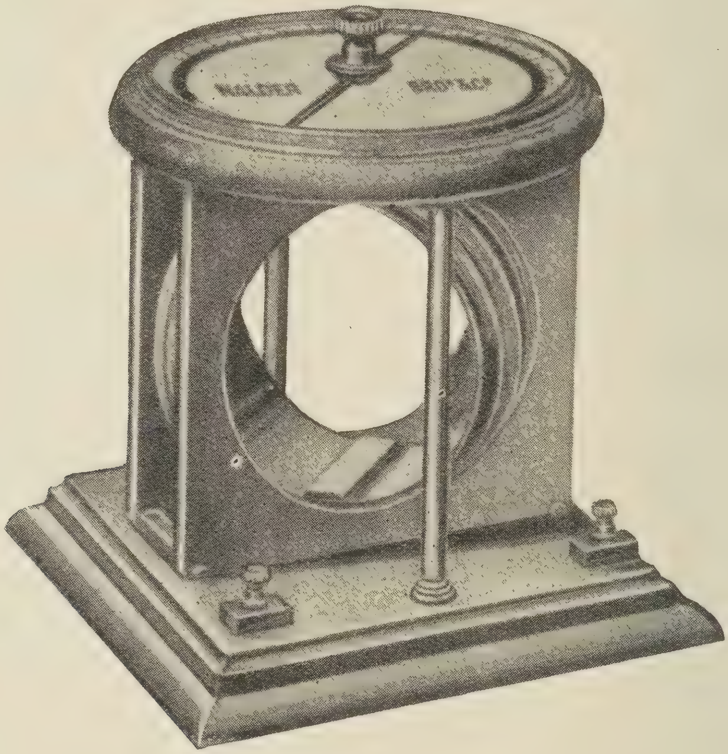


FIG. 125. The Ayrton-Perry Self-Inductance Standard referred to in the text.
With the permission of Messrs. Nalder Bros. & Co.

them their bearings. An interesting account of this work on the British Commercial Airways was given by **Duncan Sinclair** in a paper before the Wireless Society of London in 1921 (586).

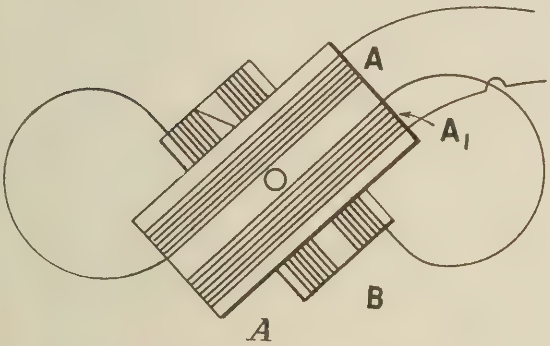
THE VARIOMETER

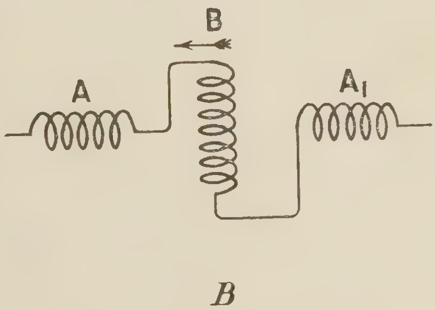
THE AYRTON-PERRY VARIABLE " SELF-INDUCTANCE STANDARD " (1), (759), (760).—The principle of the Variometer was employed in the design of the Ayrton-Perry Self-inductance Standard in 1886. Fig. 125 is an illustration of this instrument.

Perry's original apparatus is in the possession of the Finsbury Technical College.

THE AMALGAMATED RADIO-TELEGRAPH CO.'S "VARIOMETER" (157).—In their 1907 patent the Amalgamated Radio-Telegraph Co. cover the use of a "Variometer," or Variable Inductance, in the aerial circuit of a wireless installation.

THE TELEFUNKEN CO.'S "VARIABLE INDUCTANCE" (85).—Between 1909 and 1911 this Company fitted their transmitting sets with flat spiral inductances in both open and closed circuits. Spirally wound coils were arranged in parallel and close to one another in a frame, alternate coils being connected to a lever handle by means of which their position relative to the others could be varied. The coils were connected so that the currents in adjacent coils opposed each other and decreased the self-induction of the whole. A movement of the lever handle would separate them, and so regulate the total self-induction.





FIGS. 125 A and B. Illustrate one of the methods of connecting the windings of a common type of modern variometer.

THE MODERN VARIOMETER.—Fig. 125A illustrates one scheme of connections for the variometer. The outer winding is divided into two portions A and A_1, and the inner winding B is connected between A and A_1, as shown in Fig. 125B. To increase the amount of inductance, the inner coil can be rotated so that its windings are in the same direction as those of A and A_1. To reduce the amount of inductance, it is rotated in the opposite direction, so that its windings are in opposition to A and A_1.

S. EISENSTEIN'S METHOD OF VARYING SELF-INDUCTION (869).—In 1908 **Eisenstein** was granted a British patent for a

method of varying the mutual induction between flat spirals by placing two such spirals with their flat surfaces in close proximity and then moving one of them rectilinearly over the other.

One of his methods was to fix one spiral in the bottom of a box, and the other in a drawer just above which could be slid in and out to the degree desired.

High-frequency Alternators

Fessenden's Alternators.—As a result of his work during 1901 and 1902 (419), (420), in 1903 (50) **Fessenden** constructed the first alternator capable of producing alternating current at a frequency sufficiently great to employ for the direct excitation of a transmitting aerial; and in 1906 he had so greatly improved upon its construction that he was able to obtain frequencies up to 50,000 (411). This alternator was one of the "Mordey" type. The armature was fixed, and took the form of a thin disc. The field magnet, which had 360 polar projections, revolved at a speed of 139 revolutions per second. It gave an E.M.F. of 65 volts, an A.C. of 50,000 cycles, and a maximum output of 0·3 kilowatt.

Fessenden later designed and operated an alternator giving an output of 2 kilowatts, at a frequency of 100,000 cycles (50), turbine driven.

He also designed alternators capable of working at a frequency of 200,000 cycles (50).

Alexanderson's Alternators.—**E. F. W. Alexanderson** has greatly improved on the inductor type of machine (421), (422), (423), and has designed alternators capable of giving an output of over 200 kilowatts.

In 1918 (423) a 200-kw. Alexanderson Alternator was installed at the New Brunswick station (call letters NFF), and has given consistently satisfactory results. It is run at an output of 80 kw., and gives an aerial current of 400 amperes, and is actually capable of supplying 600 amperes. The normal wavelength employed is 13,600 metres.

Franklin's Alternator.—**C. S. Franklin** (430) patented, in 1913, an alternator which generates high-frequency currents without the necessity of running the rotor at excessive speeds.

E. Girardeau and J. Bethenod's High-frequency Alternator (424), (431).—**Bethenod** increases the output of H.F. alternators by providing them with two-phase windings and arranging that both phases are employed to excite the aerial. A 350-kw. alternator of this type has been installed at Lyons.

Other Alternators.—High-frequency alternators have also been devised by **L. Bouthillon** (425), (762), (763), **Marias Latour** (426), (427), **A. M. Taylor** (762), (763), and others.

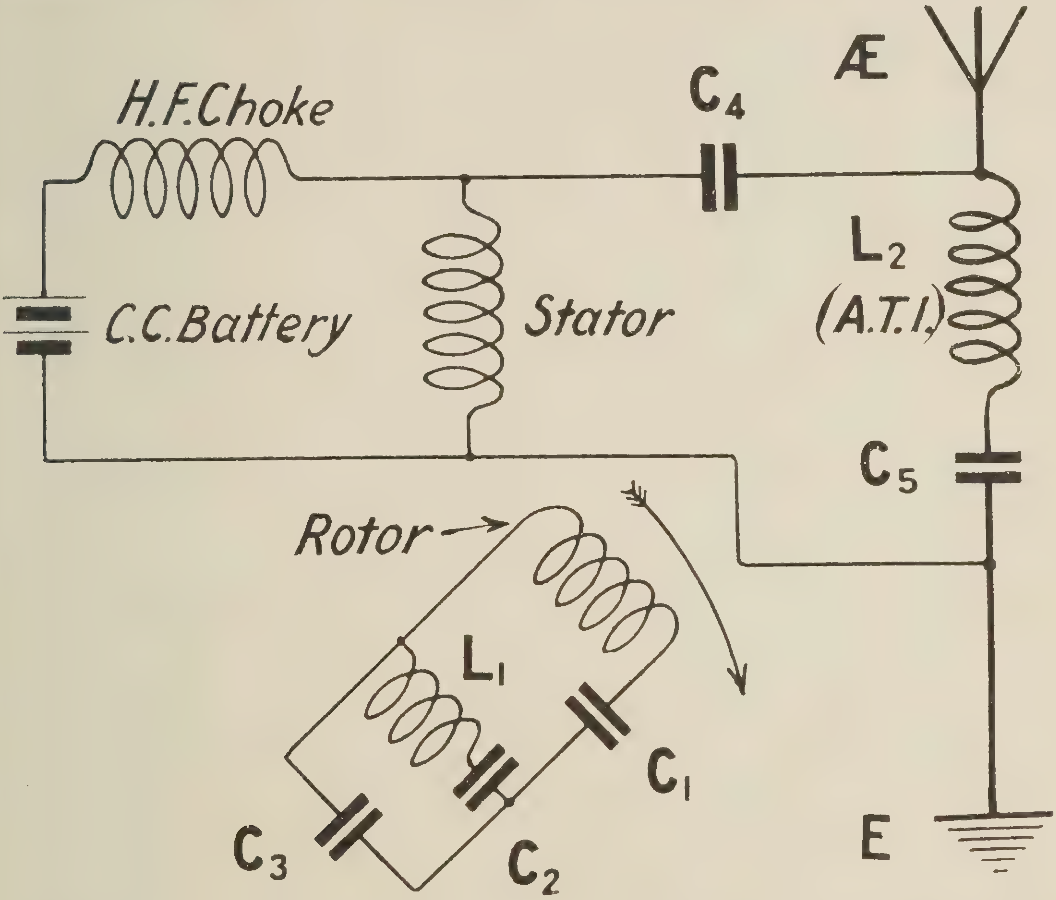


Fig. 126. Illustrates the principle of the Goldschmidt Alternator. In actual practice the source of supply is a D.C. generator.

Rudolf Goldschmidt's Reflection Alternator (412–418), (428).—In 1909 * **Goldschmidt** took out patents for an alternator based on similar principles to those employed by Cohen (432).

The following brief description gives some indication of the principles upon which this machine works :

The rotor of the machine is run at, say, a peripheral speed of 150 metres per second, at which speed a frequency of

* It was in this year that Marconi opened a public service between Clifden in Ireland and Glace Bay, Nova Scotia.

15,000 cycles is generated therein; these currents induce others of double this frequency in the stator, *i.e.* 30,000 cycles. These, again, induce currents having a frequency of 45,000 cycles in a circuit containing a suitable capacity shunting the rotor. These currents, again, set up others of 60,000 cycles in a circuit connected to the stator. Fig. 126 is a diagram showing the general arrangement.*

Machines of this type have been constructed for outputs of about 150 kw., and have been employed successfully for transatlantic telegraphy. The radio station at Laeken, Brussels (108), (429) was equipped with a Goldschmidt Alternator for an output of 250 kw., but the entire station and apparatus was destroyed at the commencement of the Great War.

KORDA'S TRIPLE-FREQUENCY RAISER.†—This alternator is fitted with two rotors mounted together on one shaft, and each having one stator. The arrangement is somewhat similar to the Goldschmidt alternator, and increases the initial frequency three times.

PETERSEN'S FREQUENCY RAISER (108), (433).—This was patented in 1912, and consists of a series of rapidly-variable condensers connected to suitable circuits, as shown in Fig. 127. Each condenser consists of two fixed plates and two rapidly-revolving ones, as shown.

STATIC FREQUENCY RAISERS.‡—The origin of static frequency raisers, (*i.e.* frequency raisers in which no moving parts are employed), is usually attributed to **Epstein**, in 1902 (108), (434). Fig. 128 is a diagram of a few of the methods employed.

VALAURI'S FREQUENCY RAISER.—Fig. 128A shows **G. Valauri's** method, invented in 1911 (436), (108). T, T_1, T_2 are the three limbs of the iron core of a transformer; a winding W round the centre limb T_1 is connected to a constant current battery B which magnetises the core. This renders the current wave non-sinoidal, and produces prominent double-frequency harmonics.

JOLY'S FREQUENCY TRIPLER.—Fig. 128B shows the arrangement of **Joly's** frequency tripler (435). In place of using a

* A full description of the Goldschmidt Alternator will be found in "The Electrician" for July 19th, 1912.

† A description of this alternator is given, with diagrams, in P. R. Coursey's book, "Telephony without Wires."

‡ See also M. Latour's Static Frequency Changer (793).

constant magnetising current, Joly magnetically saturates one transformer and only lightly magnetises the other. The secondary circuit S is tuned to the triple frequency by means of a variable condenser C. The secondaries of the two transformers are wound in opposition, and the fundamental frequency in this circuit is thereby practically neutralised. The action of this apparatus is very critical, and depends upon the relationship of the degrees to which the two transformers are saturated.

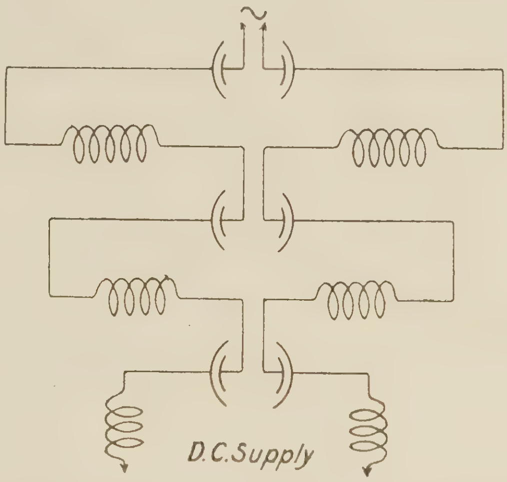


FIG. 127. A circuit showing the arrangement of Petersen's Frequency Raiser. The rotating condensers are indicated in the centre of the diagram.

TAYLOR'S FREQUENCY RAISER.—Fig. 128C shows one form of **A. M. Taylor's** frequency raiser (108), (437), (438). Another and better arrangement of Taylor's is to employ a three-phase current supply, and three sets of chokes and transformers the secondaries of which can either be connected in series or in parallel ; or three separate chokes may be employed, each having a separate primary winding arranged around one limb of a common iron core, one secondary winding being arranged on its other limb.*

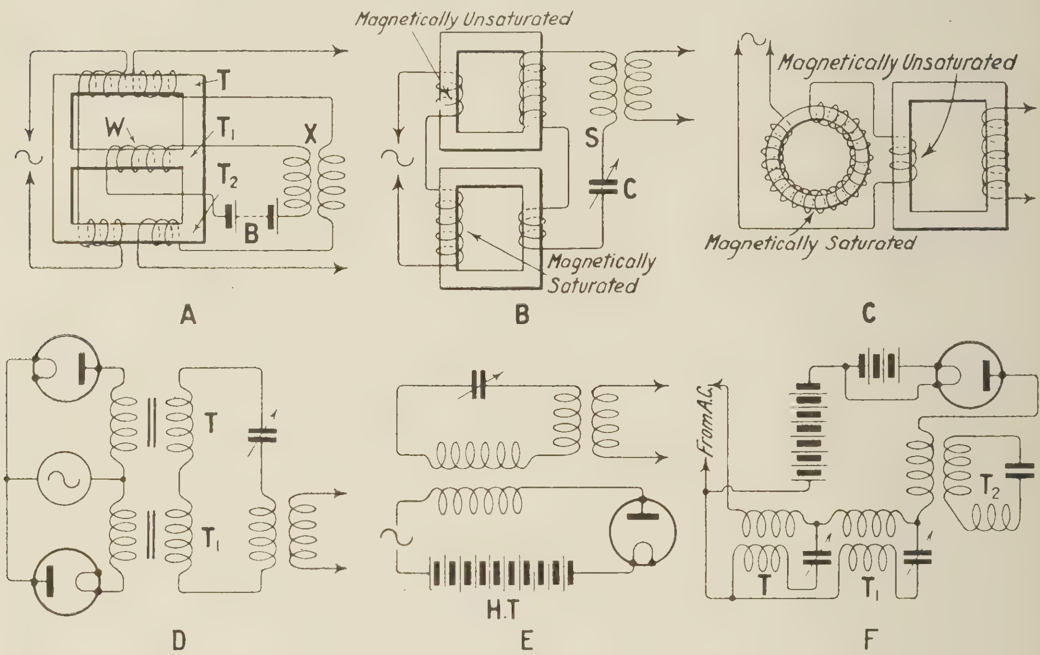
FREQUENCY RAISERS IN WHICH THERMIONIC VALVES, MERCURY VAPOUR LAMPS, ELECTROLYTIC OR OTHER MEANS OF RECTIFICATION MAY BE EMPLOYED.

ZENNECK'S FREQUENCY DOUBLER.—Fig. 128D shows a method employed by **J. Zenneck** (442), in which two transformers, T and T_1, are employed, and connected so that all the negative half-waves pass through the primary of one, and all the positive half-waves go through the primary of the other.

* Other frequency raisers of a somewhat similar character have been devised by T. Kujirai (438), (439), F. Spinelli (440), I. Schoenberg (441), M. Latour (741), (742) and others.

Franklin's Frequency Raiser.—Fig. 128E shows a method due to **C. S. Franklin** in which only one valve is used (443).

Franklin's Multiple-frequency Raiser.—For still further increase of frequency **Franklin** employs the arrangement shown in Fig. 129F. The frequency at the secondary of transformer T will be twice the frequency of the A.C. supply. At transformer T_1 the frequency will be four times the fundamental



Figs. 128 (A to F). Illustrate the main circuit details of the various types of static frequency raisers referred to in the text.

frequency, and the frequency in the final circuit T_2 will be eight times that of the alternator.

The main object of the foregoing frequency raisers has been to obtain an increase of frequency from comparatively low frequency alternators.

Use of Frequency Raisers for Reception.*—**John Scott-Taggart** (444), (651) and others have suggested frequency multiplication for increasing the selectivity of reception. The controlling factor in selective reception is the frequency difference between the two wave-trains.

The frequency in cycles for a given wavelength in metres is found by dividing the wavelength into 300,000,000 (the speed of light in metres per second).

* See also E. H. Armstrong's method of Short Wave Amplification by Reduction of Frequency (Chapter XV.).

For instance: 1,000 metres equals 300,000 cycles per second (300 kilocycles); while 10,000 metres equals 30,000 cycles per second (30 kilocycles).

From this it will be seen that as the wavelength increases the frequency diminishes, so that for a given wavelength difference in the higher wavelengths, there is a much smaller kilocycle difference than for the same wavelength difference on the lower wavelength, and consequently there has to be a very much greater difference between the wavelengths of two long-wave stations, to prevent interference.

On a 1,000-metre wavelength a difference of 10 metres either way will easily prevent jamming, but as the wavelength rises, with consequent frequency diminution, a much wider wave band becomes necessary for each station. The wavelength separation given in the particular instance above does not hold for telephony transmissions; in the latter case a 10-kilocycle band for each station is usually considered a safe practical limit.

Scott-Taggart suggested that by the employment of frequency raisers in receiving circuits, greater selectivity could be secured, and room made for more stations than would be otherwise possible.

Suppose, for instance, two stations were working, one on 16,000 metres and the other on 16,100 metres, respectively, their signals would jam, there being a difference between them of only about 116·5 cycles. If, however, we multiply the frequency of both stations by 10, they can then be received on wavelengths of 1,600 and 1,610 metres respectively. There is now a frequency difference of 1,165 cycles between them, and it will be possible to receive one without the other. The multiplication of frequency need not, of course, be limited to 10 times. It may be taken up to 100 times, or even more.

C. Bardeloni's Method of Separating Simultaneously Received Radio Signals (791).—Fig. 129 shows the method described by **Bardeloni** in 1922 for separating two or more signals received simultaneously. This scheme was employed during the Great War and proved quite workable, provided the signal strengths differed. D is a crystal detector (carborundum and steel) in series with two dry cells B, and connected between the grid of a triode valve G and the sliding contact of a potentiometer P fed by the filament battery B_1.

The crystal rectifies the received oscillations, and the valve is arranged for simple amplification.

When two signals of different strength are being received it is possible, by suitably adjusting the slider of the potentio-

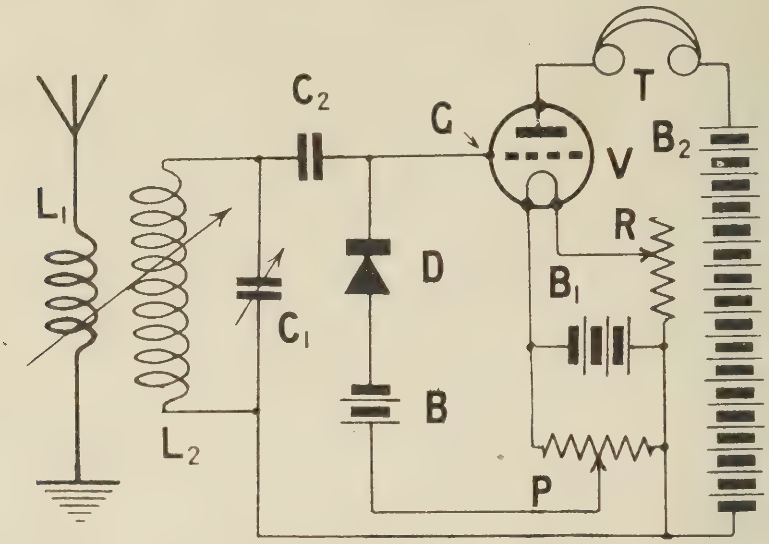


FIG. 129. Bardeloni's method for separating signals which are received simultaneously but are of different intensity.

meter, to receive only one signal: the weaker one is not amplified, but the stronger one is.*

The same device is also employed for the reduction of static interference.

* In 1924 The **Author** suggested the employment of a hot wire Microphone for a similar purpose to the above. See pages 205-207.

CHAPTER XV.

THE THERMIONIC VALVE * AND SOME OF THE FUNDAMENTAL VALVE CIRCUITS

LEE DE FOREST.—In the summer of 1900, while **Dr. Lee de Forest** (466) was engaged in some experiments in Wireless Telegraphy, he noticed that every time he switched on a small spark coil, a decided diminution took place in the illumination of the room from a Welsbach gas burner, the distance separating the coil from the burner being about 10 feet. He therefore carried out a careful investigation into the phenomenon, and he soon came to the conclusion that " heated gas molecules were sensitive to high-frequency

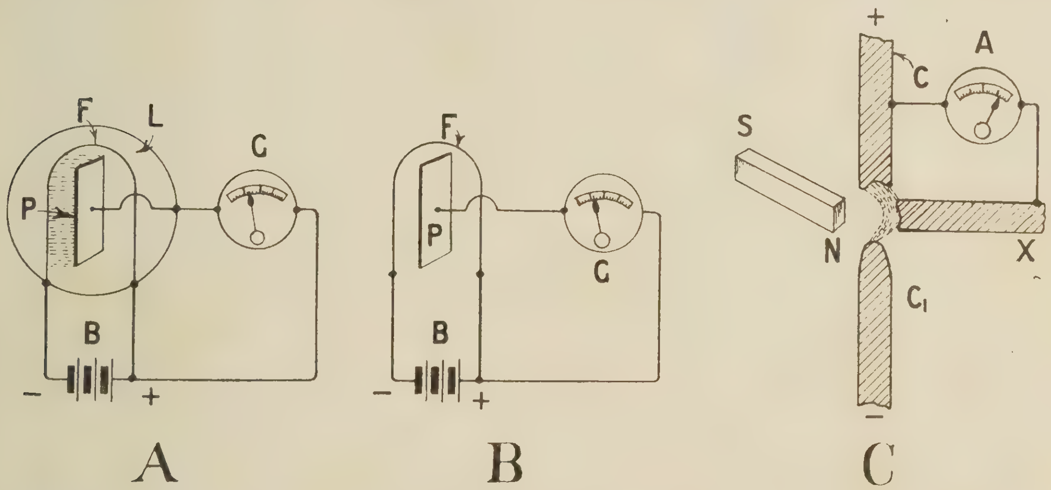


FIG. 130. **A** illustrates the Edison effect referred to in the text, and **B** shows how the same effect was produced in air by Fleming at a later date. **C** indicates one of the arrangements used by Fleming in his electric arc experiments.

electrical oscillation." Three years later, in 1903, he invented the flame detector (845),† and during this same year he successfully employed the flame detector to receive signals from ships in New York Harbour.

FLEMING.—While De Forest, in America, was leading onwards by these researches to the then imminent discovery

* For construction of thermionic valves see Refs. (499) and (780).

† In 1920 **C. W. Heaps** (577) carried out some experiments with a Bunsen flame fitted with three electrodes. A small piece of sealing-wax was placed on the cathode. This, when heated, yielded a plentiful supply of electrons. With this arrangement he obtained amplification.

Reference should also be made to **Mellinger's** flame audion in Chapter X. of this book, and to the **Author's** experiments with a Bunsen flame detector in 1911 (578).

of the " Soft " Thermionic Valve, **Professor Fleming,** here in England, was conducting a research along another line of investigation, which led him to the discovery of the thermionic valve in 1904 (484), (485).

THE EDISON EFFECT.—The Fleming Thermionic Valve was the outcome of an effect noticed by **Edison** in 1884 (1), (445), (446).

Fig. 130A is a diagram illustrating the Edison effect. L is a small incandescent carbon filament electric lamp. F is the filament maintained at incandescence by means of a battery B. Edison showed that if a small metal plate were placed between the two sides of the bent filament, as shown, a current (*i.e.* a stream of electrons), passed from the negative leg of the filament to the plate. This was detected by a galvanometer G connected from the plate to the positive side of the filament battery.

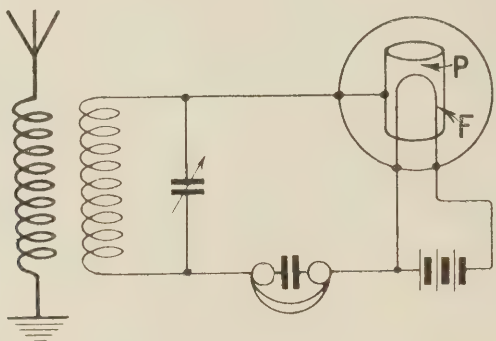


FIG. 130D shows the connections to a Fleming two-electrode detector valve. P and F represent the plate and filament.

SIR WM. PREECE.—In 1885 **Sir Wm. Preece** communicated a paper to the Royal Society, in which he showed that particles were projected from the filament to the plate in straight lines.

J. A. FLEMING.—In 1889 **Prof. J. A. Fleming** communicated a paper to the Royal Society, in which he showed that these particles carried a charge of negative electricity, and that they could be employed to convey a current of electricity in one direction only.

SIR J. J. THOMSON.—In 1897 **Sir J. J. Thomson** (471) definitely proved the existence of " electrons," by which name we now always speak of these tiny negative entities.

J. A. FLEMING.—In 1890 **Prof. J. A. Fleming** (1) produced the Edison effect in air. (Fig. 130B) During the same year,

Fleming showed a very similar phenomenon in connection with the electric arc.*

A DC arc is struck between two carbons, as shown in Fig. 130C, and is deflected outwards on to an " exploring " electrode X (also of carbon). He obtained a large reading when a galvanometer A was connected between X and the positive carbon C. When he changed the galvanometer connections and connected it between X and C_1, no deflection was observable in the galvanometer.

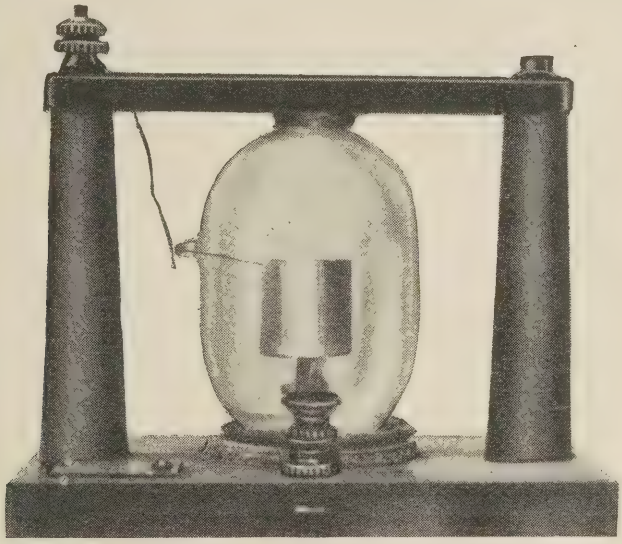


FIG. 131. An early type of Fleming two-electrode valve, mounted in a frame provided with terminals for connection to the electrodes.

FLEMING'S TWO-ELECTRODE VALVE (469), (4D), (753), (877), (878).—In 1904 **Fleming** showed that a carbon filament incandescent electric lamp, surrounded by a metal plate, acted as a rectifier for H.F. oscillations, and could be employed as a detector for wireless, and at this date he took out his original patent (464),† in which he termed it a " Thermionic Valve."

As detectors, these two-electrode thermionic valves were not quite so sensitive as a good crystal or electrolytic detector ; but they were more constant and generally reliable in use.

Fig. 130D shows the circuit employed, and Fig 131 is a photograph of one of Fleming's earliest two-electrode valves, reproduced by permission of the Marconi Company.

* An account of **Fleming's** actual experiments is given in *The Electrician*, February 28th, 1890.

† British patent (464). Also U.S.A. patent (448) ; and German patent (449).

FLEMING'S TUNGSTEN FILAMENTS.—In 1909 **Fleming** suggested the employment of tungsten for the filaments of valves. (471), (465).

DE FOREST'S GAS-FILLED MOLECULAR DETECTOR.—Reference should also be made to **Lee de Forest's** gas-filled molecular detector (852), described in Chapter VII., page 91.

MARIUS LATOUR'S MERCURY VAPOUR TUBE (467).—In 1905 **Latour,** in conjunction with **Weintraub,** designed a mercury vapour tube, for the purposes of amplification. The tube had one mercury cathode, and two anodes. They discovered experimentally that the potential drop between the cathode and one anode for certain values of current decreased if the current was increased. When the tube was connected in a circuit carrying weak alternating currents, these currents were amplified by virtue of the negative resistance effects of the tube.

THE THREE-ELECTRODE VALVE

(Named by Eccles " The Triode ") (450) (451), (452), (466), (490 to 494), (753), (769).

DE FOREST'S " AUDION."—In 1906 **De Forest** added a third electrode or grid to the **Fleming** valve. The valve in this form has completely revolutionised modern radio practice, and many uses have been found for the valve in other branches of science.

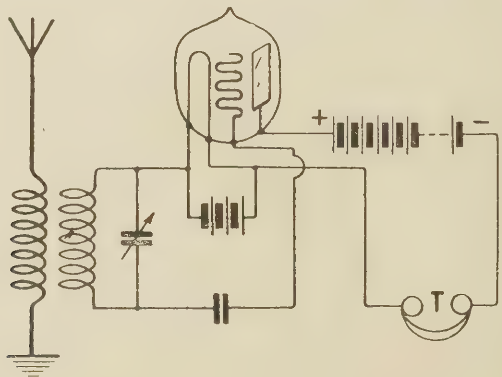


FIG. 132 shows the arrangement of De Forest's " Audion " in a receiving circuit embodied in 1908 patent, No. 1427.

His first patent (452) was taken out on June 26th, 1906. At that date he termed it the " Audion."

In 1907, in a further U.S. patent, he named the third electrode the " grid." He also took out an English patent (472) in 1908.

Very shortly after taking out his first "Audion" patent, De Forest discovered that the three-electrode valve could be employed as a telephonic relay.

In this "Audion" valve, both the anode and the third electrode were flat plates, and a portion of the electron stream was able to bombard the walls of the glass bulb, often causing irregularities in the steady anode current, unless constant adjustments were made by the employment of a potentiometer.

Fig. 132 is a diagram (taken from De Forest's patent No. 1427/08) illustrating the "Audion," and one method of making its connections.

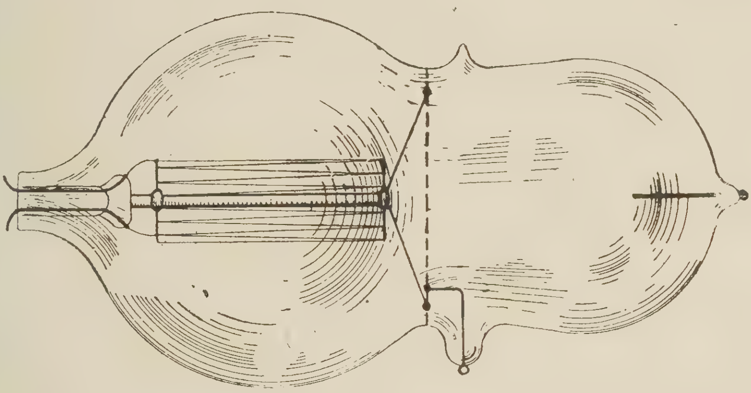


Fig. 133 shows the disposition of the electrodes in the Lieben three-electrode valve as given in the British patent.

All the earliest types of valves employed for radio reception were of the "soft" type,"* *i.e.* they were not very highly exhausted, and retained a considerable number of gas molecules.

Von Lieben's Three-electrode Valve, and the Lieben-Reisz Valve or "Gas Relay" (470), (469), (227), (108), (453), (454), (455), (92).—In 1911 **Von Lieben** (470) invented a three-electrode valve, in which the grid (a perforated sheet of aluminium) was placed right across the centre of the bulb, and divided it into two separate compartments, one containing the filament, and the other the plate. It was a "soft" valve, the interior of the bulb being only partially exhausted. The object

* **Stanley** (227) has shown that if a galvanometer connected in the grid circuit shows a reversed grid current, when the grid is made increasingly negative, this reversed current must be due to ions in the valve, and the vacuum is therefore soft This is a ready method of testing the vacuum of a valve.

of this arrangement was to compel all the electrons to go through the grid, and to shield the filament from bombardment by positive ions. The greatest defect in this valve was that a portion of the cathode stream had free play against the glass of the bulb, which, on becoming charged thereby, tended to alter continually the characteristics of the valve, and correction was necessary by aid of a potentiometer.

Fig. 133 is a diagram of this valve. The containing tube is of glass, and about one foot long, divided into two compartments by an aluminium grating or grid. The upper compartment contains a rod or spiral of aluminium wire, which forms the anode, and the cathode is a platinum filament, coated with a thin layer of calcium or barium oxide.* A trace of mercury

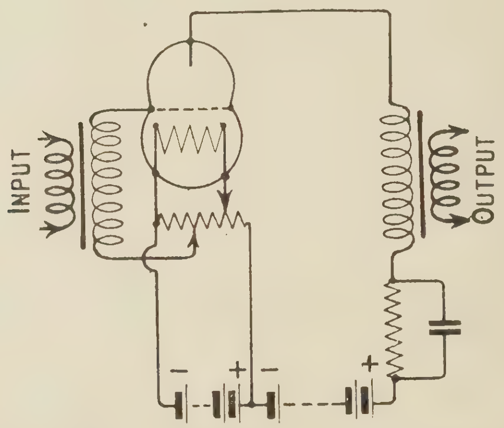


FIG. 134. The amplifier circuit used with the Lieben-Reisz valve.

vapour in the tube, which is vapourised by the hot filament, results in ionisation and a greater emission.

Fig. 134 is a diagram showing the connections of the **Lieben Reisz** Relay or Amplifier.

ARCO AND MEISSNER.—In 1914 (474), **Arco** and **Meissner** took out patents for many applications of the three-electrode valve for purposes of relaying, amplifying, and generating alternating currents. Their British patent (No. 252/1914) should be referred to. It is a very important patent.

H. J. ROUND.—In 1913 **H. J. Round**, in his patent No. 28413,† covered an improvement in the construction of valves. In order to prevent the cathode stream from reaching the walls

* **Wehnelt** had already employed lime-coated filaments in 1904, to obtain cathode streams in vacuum tubes run on low voltages.

† For **Round's** circuit diagrams covered by this patent see later in chapter.

of the tube, he completely surrounded the filaments F_1 (see Fig. 135) of the valve with a grid G of wire gauze, and made the plate P in the form of a cylinder surrounding the grid. The latter was open at both ends.

It will be seen that the top of the grid completely enveloped the filament, which was placed near the closed end of the grid. The latter extended downwards far past the incandescent filament.

ROUND'S MULTI-FILAMENT VALVES.—Two or more filaments were fitted as shown in the diagram. The pip R at the top of the valve was blown out so as to form a little chamber, in which was placed some material M, which, on being heated, was capable of supplying a minute quantity of gas in order to increase the number of gas molecules in the tube, and so soften its vacuum.

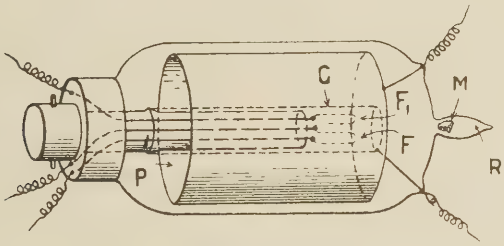


FIG. 135 shows the construction of Round's soft vacuum valve.

FRENCH R VALVE.—During the Great War the French military authorities at " L'Etablissement Centrale de Télégraphie " (227), under the direction of **General** (then Colonel) **Ferrié,** constructed the now so well known French valve. It is of the Pliotron or hard valve type,* but it is far simpler in design, and became, during the War, the standard type for both reception and amplification for the Allied Armies. This valve functioned well with a filament current of 0·52 amps., at 3·72 volts, and a plate voltage of 75.

This was patented by **Peri** in 1916 (475).

OTHER TYPES OF R VALVE.—There are now numerous R valves upon the market, manufactured by Marconi Osram, Mullard, British Thomson-Houston, Ediswan, Cossor, Radions, Burndept, etc.

* For information *re* the " Pliotron," and the introduction of the hard valve by **Langmuir** in 1915, see later in chapter.

Marconi Co. Q Valve.—Another good type of valve, designed by **H. J. Round,** was that known as the Marconi Q type valve, a tubular shaped valve with a bulb about 3ins. long and $\frac{11}{16}$ ins. in diameter. The plate is similar to that in a French R valve. The filament functions on a current of ·45 amperes at 5 volts. The original Q valves were designed for a plate voltage of from 150 to 200 ; but Q valves of later design function well on much lower plate voltages.

German Valves.—In Germany, during the early part of the war, several types of valve were constructed for detection and amplification ; but none of these equalled the French R valve. The filament in the German valve was not enclosed by the grid and plate ; but the two latter electrodes were in the form of a flat spiral and a metal disc respectively, and were placed below the filament. Valves of this type were constructed by the A.E.G. Co., the Telefunken Co., Siemens and Halske, and others (227).

The amplification factor of these valves is much less than that of the French R type ; but they do not readily oscillate and are very silent. Towards the end of the War, the Germans, notably the Telefunken Company, no doubt after they had captured samples of the French valves, reproduced valves having similar characteristics. One of the best examples of these was made by the Telefunken Company, and known as the type E.V.E. It was very similar to the French R valve ; but the four connection pins at its base were so designed that they would only fit into plugs designed specially to receive them, and would not fit into the French R valve socket.

In 1918, owing to scarcity of nickel, the Germans employed copper in place of nickel for grids and plates. One of their best valves was known as the R.E.16. It took a smaller filament current than the French R valve.

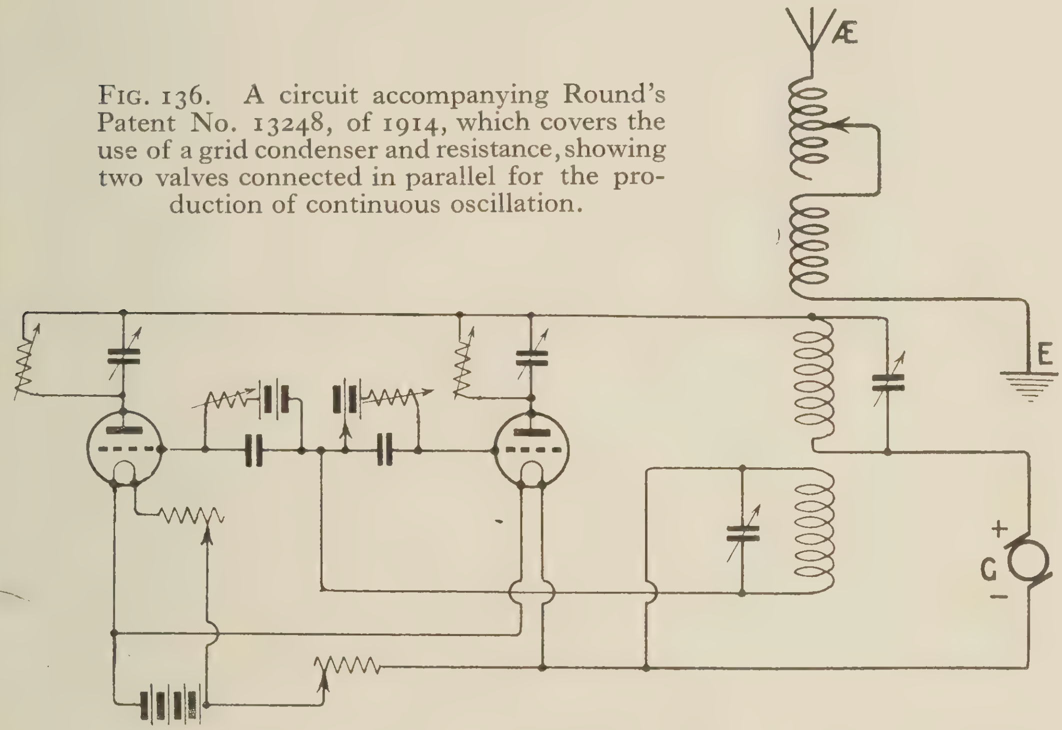
Round's Grid Condenser and Resistance.—In 1914 **H. J. Round** took out a patent, in conjunction with the Marconi Company (447),* under the title of "Improvements in the production of continuous electrical oscillations, and in the utilisation thereof for wireless telegraphy and telephony," in which he covers the employment of a small condenser in the grid circuit, which he bridges by means of a high

* Reference should also be made to the **Arco** and **Meissner** British patent No. 252, 1914—Methods of producing undamped oscillations by means of valves. Also to the work of **Langmuir**—Refs. (457–460).

resistance, in series with a battery (with or without a potentiometer). He also employed a resistance in the plate circuit to limit the heating of the valve, and consequent liberation of occluded gases ; and covered the employment of a number of valves in parallel. He also suggested cooling the valve by means of an "oil jacket."

VALVES IN PARALLEL.—Fig. 136 is one of the circuits given in his patent specification, showing two valves in parallel, each fitted with a grid condenser and resistance and also plate circuit resistances.

FIG. 136. A circuit accompanying Round's Patent No. 13248, of 1914, which covers the use of a grid condenser and resistance, showing two valves connected in parallel for the production of continuous oscillation.

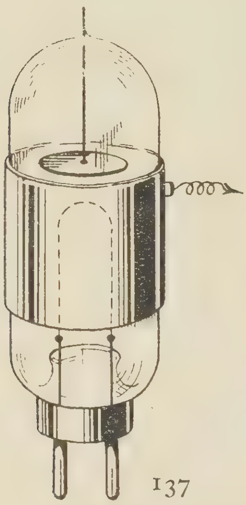


R. WEAGANT'S THREE-ELECTRODE VALVE (WITH EXTERIOR ELECTRO-STATIC CONTROL).—In 1914 **R. Weagant,** Chief Engineer of the Radio Corporation of America (456), (990), constructed the three-electrode valve shown in Fig. 137. The third electrode is removed from inside the valve, and the electron stream, within the bulb, is controlled by the electrostatic field of a metal sheath, placed outside the tube. This valve is very much cheaper to manufacture, and can be employed in any of the well-known circuits, but is not in practice so efficient as a valve with an internal grid.

H. J. ROUND'S VALVE (WITH EXTERIOR ELECTRO-MAGNETIC CONTROL).—A valve controlled by a magnetic field was patented by **H. J. Round,** and the Marconi Co., in 1914 (486).

A circuit employing this valve for the production of continuous oscillations is shown in Fig. 138. The glass bulb is constricted as shown, and a metallic coating S of wire or foil is placed around the constricted portion. In the region between the filament and plate, and on each side of the constricted portion, the poles of a control-magnet MM_1 are arranged.

R. A. Weagant's Valve, with Connection at Centre of Filament.—In 1916 **R. A. Weagant** invented a valve with a lead to the centre of its filament (991) for connection to the oscillatory circuit.



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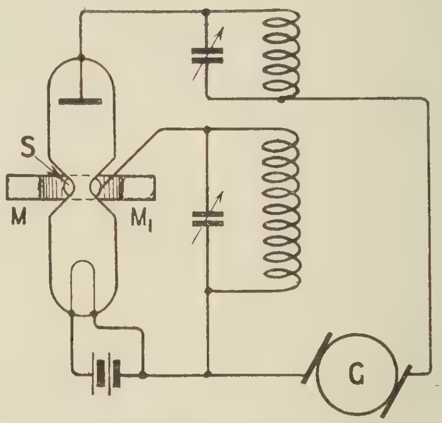

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Fig. 137 (left). Weagant's three-electrode valve with external grid.

Fig. 138 (right). An oscillator circuit using Round's three-electrode valve with external grid. MM[1] represent the poles of the control magnet.

A Non-interfering Detector Valve.*—In 1922 **Harold P. Donle** (of the Connecticut Telephone and Electric Company) invented an entirely new type of valve, which he described in a paper before the Institute of Radio Engineers (487). This valve is an extremely sensitive detector, and is claimed by the inventor to be "at least equal to a regenerator with the most critical regeneration." The extreme sensitivity is secured by the employment of metallic ionization, and a new form of electrode in the tube, called by the inventor a "Collector."

The valve and its connections are illustrated in Fig. 139A and 139B.

* See also the Sodion Detector—Ref. (743). Also Refs. (789), (828), (222), and (1098).

G is an exhausted glass bulb, containing a filament F, which, when incandescent, emits electrons on to an anode S. The latter is an easily-vapourised metal, such as sodium. Almost as soon as the filament current is switched on, an emission of particles begins to take place from the anode, which would gradually dwindle to a small fraction of its initial value. This decay in emission is, however, entirely corrected by means of a heating element H outside the walls of the tube. This corrects the amount of ionization, and keeps the tube in constant working condition, over long periods of

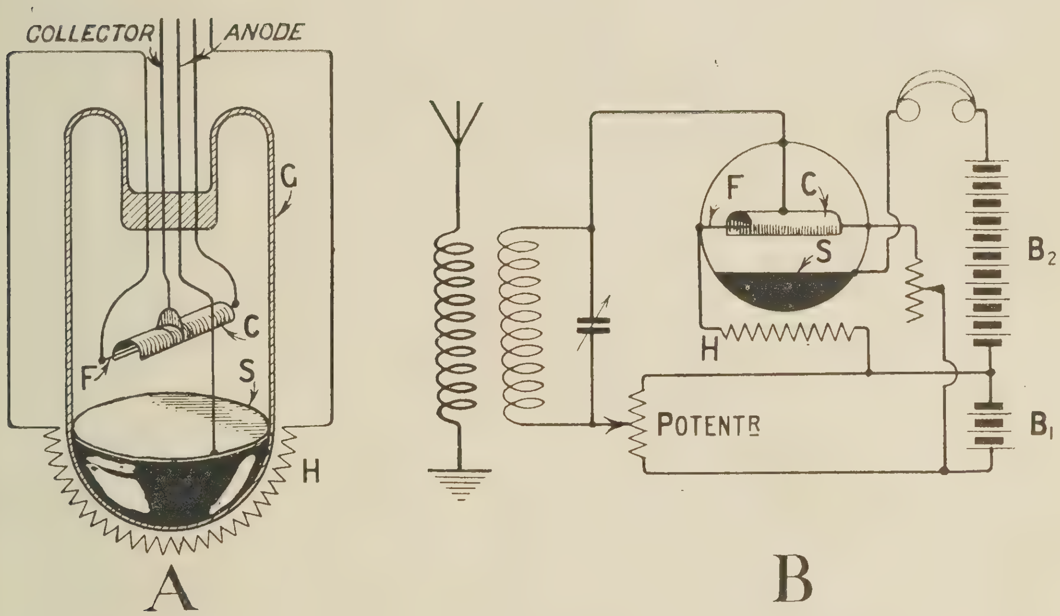


FIG. 139. **A** shows a diagrammatic representation of Donle's "Sodion" detector valve, and **B** indicates its connections in a receiving circuit.

time. C is a new type of metal electrode, half surrounding the filament on the side remote from the anode, and called the "Collector." The normal potential of the collector is controlled by means of a potentiometer, and it is most necessary to regulate it, so that the electron flow from the filament to the collector may be neutralised. Very small variations in the voltage of the collector produce large changes of anode current.

This valve is incapable of oscillation through its entire effective sensitive range, and therefore cannot radiate and cause interference with neighbouring stations.

The anode potential from battery B_2 is not at all critical. It can be anything between 10 and 30 volts.

THE THERMAGNION (498).*This is another type of valve, in which the plate current is controlled by means of an external magnetic field.

Donisthorpe has shown that a "soft" thermionic valve, having a cold cathode, could be employed as a detector. Fig. 140A shows his connections. The two windings L and L_1 are made round the outside of the exhausted bulb, around the space between the anode and cathode, as indicated.

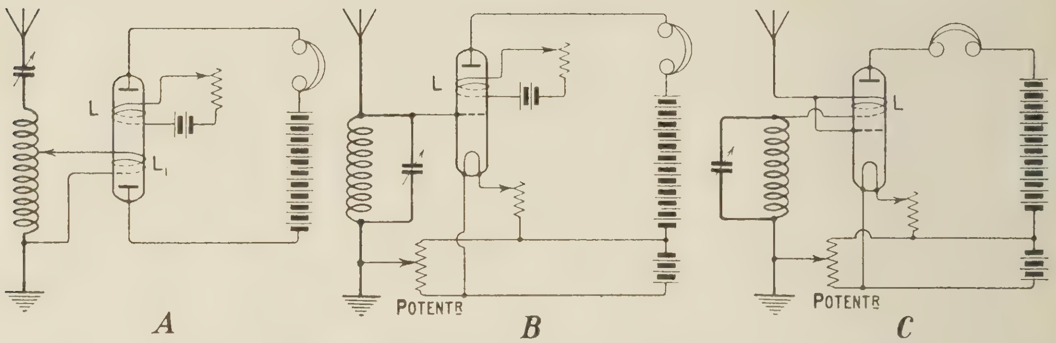


FIG. 140. **A**—The cold cathode detector circuit referred to in the text. **B**—A "Thermagnion" detector circuit with a magnetic control coil L. **C**—In this arrangement a control coil L is included in the aerial circuit.

Fig. 140B shows another Thermagnion arrangement, in which a winding is placed round the bulb of a suitable soft three-electrode valve. By adjusting the position of the coil L and the strength of the magnetic field the slope of the characteristic curve of the valve can be made much steeper, and considerable increase of signal strength is obtained. It is also possible to make the valve oscillate, so that it will detect C.W. signals.

Fig. 140C is a circuit suggested by Donisthorpe in which a control coil L is included in the aerial circuit.

THE MAGNETRON (502), (778). See also Axially Controlled Magnetron (171).—The American General Electric Company have constructed a gigantic valve called by the inventor, **Dr. A. W. Hull,** the Magnetron. This valve is capable of dealing with 1,000 K.W. The tungsten filament which runs down the centre of this valve is 22ins. long and 0·4in. in

* Reference should be made to **De Forest's** 1906 patent (852). See Chapter VII (Fig. 51), in which an external magnetic field is employed. Also **Round's** electro-magnetically controlled valve, patented in 1914 (486). See Fig. 138. Also the valve recently patented by **E. V. Robinson** (757 and 758), in which the solenoid or winding producing the field is placed inside the valve. Also the Magnetron (502), (171), (223).

diameter. The filament heating alone requires about 20 K.W. The filament is surrounded by a water-cooled cylinder, which constitutes the anode. This is 30ins. long, and $1\frac{3}{4}$ins. in diameter. The large current passing through the filament produces a magnetic field of sufficient strength to cut off the emission of electrons during a portion of each half cycle of the filament current.

With a filament A.C. supply at 10,000 cycles, interruptions would occur 20,000 times per second. Experiments have since been made with thoriated filaments, in order to increase the efficiency of this valve, and lessen the current required to heat the filament.

LANGMUIR'S HARD VACUUM VALVE (457), (458), (459), (460).—In 1915 **Dr. Irving Langmuir** conclusively proved that the presence of gas molecules in a tube was not necessary. He produced a high vacuum* three-electrode valve called the

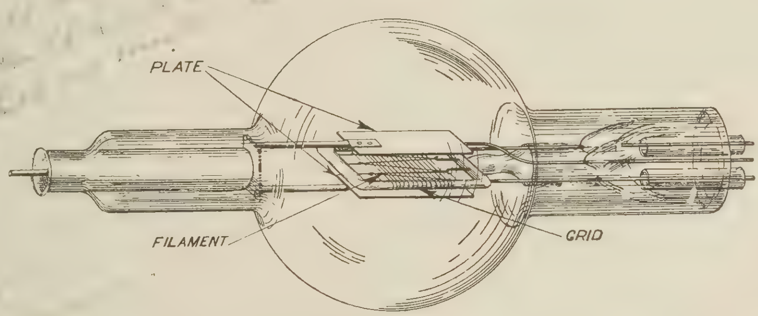


FIG. 141 shows the appearance and arrangement of the electrodes of a Pliotron power valve.

"Pliotron,"† which he described before the Institution of Radio Engineers, in September, 1915; and a hard vacuum two-electrode valve called the Kenotron, designed for the rectification of high-voltage currents. The former has been designed in small sizes for detection and amplification, and in large sizes as a power valve.

Many forms of this valve have been patented, amongst others transmitter valves for working on voltages up to 100,000 volts (108).

THE PLIOTRON.—Fig. 141 is a diagram of a Pliotron Power Valve. In America, during 1922, satisfactory tests were made

* **Fleming** had already called attention to the advisability of a high vacuum, to avoid disturbing effects due to ionization of residual gases, in his fundamental patent specification of 1904 (464).

† See also **William C. White** (463) and **Saul Dushman** (461).

at Rocky Point, Long Island. Six 20 K.W. pliotrons were employed running in parallel, and, during a 16-hour test, signals were transmitted to Nauen, in Germany. The aerial current during this test was about 310 amps.

Since the introduction of the Pliotron, much work has been done in improving the contruction of these valves in order that they may be employed with higher powers.

The Holweck Valve (744), (909), (224), (482).—This is a 10 K.W. water-cooled valve, of French invention. Two of these were put into use at the Eiffel Tower, Paris, on May

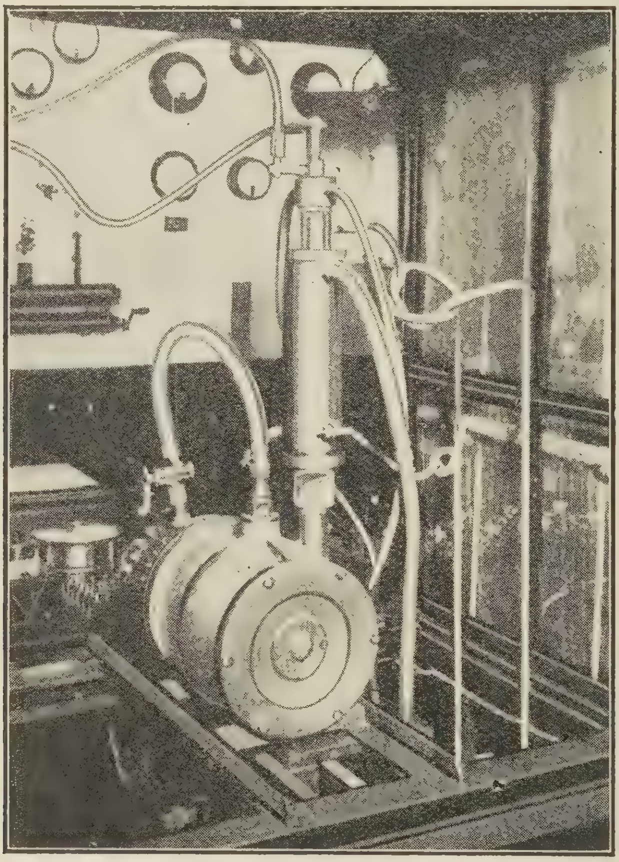


Fig. 142. A Holweck valve, installed in the telephony transmitter at the Eiffel Tower.

23rd, 1923. Fig. 142 shows one of the Holweck valves used in the telephony transmitter at the Eiffel Tower.

The various parts are assembled by means of rubber joints, so that the tube can easily be taken apart for repair. It is permanently mounted on a vacuum pump, which is in operation all the time the valve is in use . The pump was specially designed by **Holweck**, and will exhaust the valve in 30 seconds to 0·0001 of a millimetre of mercury.

Silica Valves.—The employment of high-power transmitting valves for use in the Navy dates from about 1916, and a large amount of experimental work in this direction has been carried out by H.M. Signal School at Portsmouth and the Mullard Valve Company.

With the introduction of such valves, great difficulty was experienced, owing to overheating. Oil baths were employed. Air blasts, and many other devices, were tried to dissipate the heat.

In 1919 a silica bulb was constructed, but proved unsuccessful. However, by the next year, the Mullard Company were able to supply silica valves to the Signal School, where they were exhausted and tested experimentally. In 1921 a valve was constructed, which was found quite capable of dealing with 9½ K.W. After this success, a 24 K.W. valve was constructed.

The Dynatron.—As an outcome of the work of **Dr. A. W. Hull,** during 1915–1916 (477), The General Electric Company (Schenectady), in 1918, brought out a valve, known as the "Dynatron" (476), (488), (221).

In the course of his investigations into the nature of Electricity and the Electron, **Sir J. J. Thomson** showed that if a metallic surface be bombarded by electrons travelling at a great enough velocity, the metallic surface itself emits electrons in much greater number than those originally projected on to it. Making use of this discovery, **Hull** showed that the plate current in a valve can be reduced, or even reversed, by the emission of electrons from the plate. The velocity at which the electrons travel to the plate is controlled by the voltages applied to the grid and the plate, and by suitable adjustments of these voltages; therefore, the number of electrons emitted by the plate can be similarly controlled, and if the grid potential is very positive, compared to that of the plate, the emitted electrons are attracted by the grid, which has to be made considerably more massive than the grid of an ordinary valve, in order to withstand the electron bombardment. In their Dynatron patent, the General Electric Company term the grid an "anode."

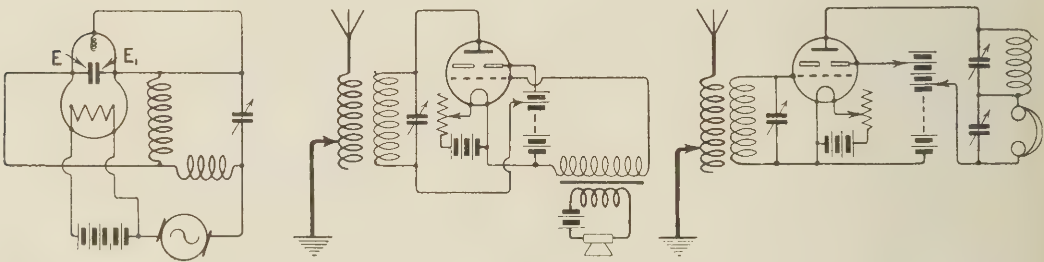
In a paper before the Institute of Radio Engineers, in 1918, **Hull** showed how a "Dynatron" could be employed to generate oscillations. He also showed how it could be

used to supply the energy losses in any oscillatory circuit by feeding back to the circuit the energy which would otherwise be dissipated by "positive resistance."

Valves with More than Three Electrodes

Several types of four-electrode valve have been invented (527).

Arco and Meissner.—Fig. 143A, which is taken from their 1914 patent (474), shows a four-electrode valve generating circuit. In the same patent a circuit for obtaining uninterrupted oscillations is shown, in which two three-electrode valves are connected in parallel so as to be operative in alternate half-periods of the A.C. supply; but experiments demonstrated, they state, "that the action of the relay (valve) and



A B C

Fig. 143. **A** shows a four-electrode valve generating circuit, working from A.C. supply, due to Arco and Meissner. **B**—A transmitting circuit employing a Pliodynatron valve. **C** shows a Pliodynatron receiving circuit.

the energy generated thereby is greater when . . . instead of the simple lattice electrode there are employed two electrodes (E, E_1) fixed opposite to one another, which electrodes form the primary path of the relay and to which the alternating current is led." They further state that these electrodes are preferably formed as interengaging combs or spirals.

Hull's Pliodynatron (488), (456), (108).—In America, **A. W. Hull** invented a four-electrode valve, which he called the "Pliodynatron." This was made by the American G.E.C. As its name implies, it is really a combination of the "Pliotron" with the "Dynatron."

Fig. 143B and Fig. 143C show the circuits employed respectively by Hull for transmission and reception with this valve.

Fig. 143D is a diagram of a Hull Pliodynatron, constructed by the American G.E.C. for transmission purposes.

FLEMING'S FOUR-ELECTRODE VALVE (489), (1009).—In 1920* **Prof. Fleming** described his four-electrode valve in a paper before the Wireless Society of London, at the Institution of Civil Engineers. He described several uses to which it could be put, and gave several circuits and characteristic curves.

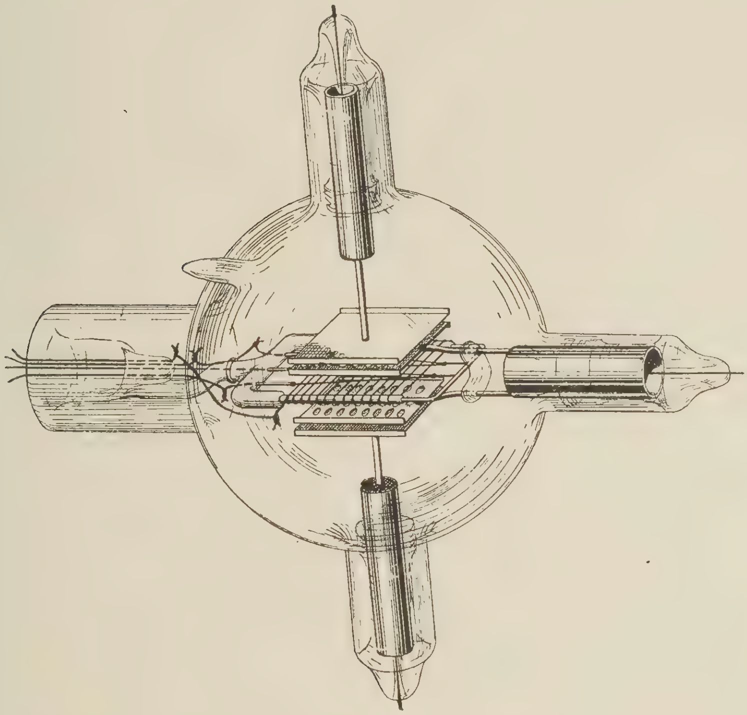


FIG. 143D shows the " plate " type of Pliodynatron transmitting valve.

Fig. 144A is a diagram of this valve. The filament, F, is surrounded by four convex metal plates, C_1, C_2, P and P_1. Plate C_1 in the diagram has been bent out of its proper position, so as to allow the filament to be seen. The valve in use is arranged as shown in the diagramatic plan, Fig. 144B, where C is the connection to the " collecting " plates, C_1 and C_2.

Fig. 144C shows the connections given by Fleming for use of this valve as a detector, operating a relay.

THE VARIABLE ANODE TAP.—It has been shown that it is often possible to increase the output of a valve generator,

* It is interesting to recall that it was during this year, on June 15th, 1920, that the Marconi Company conducted a radio-telephony test from their station at Chelmsford, on which occasion Dame Nellie Melba's voice was heard in Persia.

by connecting the anode to a point a certain distance down the aerial tuning inductance instead of connecting it to the last turn of the latter. The theory of this is given in Ref. (717).

THE WESTERN ELECTRIC COMPANY'S DOUBLE-GRID VALVE.—This valve is designed for amplifying, in connection with microphonic control in radio-telephony. Its connections are illustrated in Fig. 145.

JOHN SCOTT-TAGGART'S FOUR-ELECTRODE VALVE (1008).—**Scott-Taggart** patented a four-electrode valve, having two grids, in 1919. Fig. 145A is a circuit reproduced from the specification showing one manner in which the valve may be

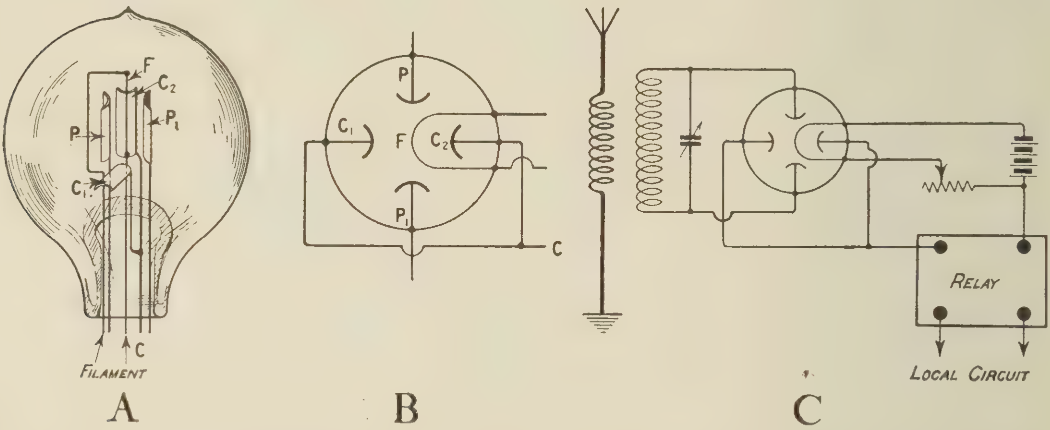


FIG. 144. **A** and **B** illustrate the arrangement of the electrodes in Fleming's four-electrode valve; **C** shows a detector circuit for operating a relay.

employed in a receiving circuit. Coupled to the aerial coil L_1 is a tuned circuit L_2 C_1, connected across the filament and the grid G_1. A suitable negative potential is applied to G_1 by a grid battery connected as at B. The second grid circuit is formed by the grid condenser C_3 and gridleak R, and the tuned circuit L_3C_2.

For C.W. reception the circuit L_2C_1 is tuned to signal frequency; the local oscillations, of such frequency as will give the desired beat note, are produced by suitable coupling between L_3 and the coil L_4 in the anode circuit, and adjustment of the condenser C_2. The grid G_1 is thus used for amplification, while G_2 is employed in connection with the rectifying process.

ANODE HEATING CONTROL. (497).—In 1921 the "Gesellschaft für drahtlose Telegraphie" patented a four-electrode valve for an entirely new purpose in radio-telegraphy, *i.e.* to

control the overheating of the valve anode. The scheme is indicated in Fig. 146.

When the anode A becomes overheated, it emits electrons, which pass to a relay electrode C, and a current flows through relay R, and the contacts at E are broken.

THE NEGATRON (501), (777), (993).—The chief use of this valve is for the production of continuous oscillations. It can also be employed for reception of C.W., as an amplifier, as a limiter, or as a radio-telephonic modulator.

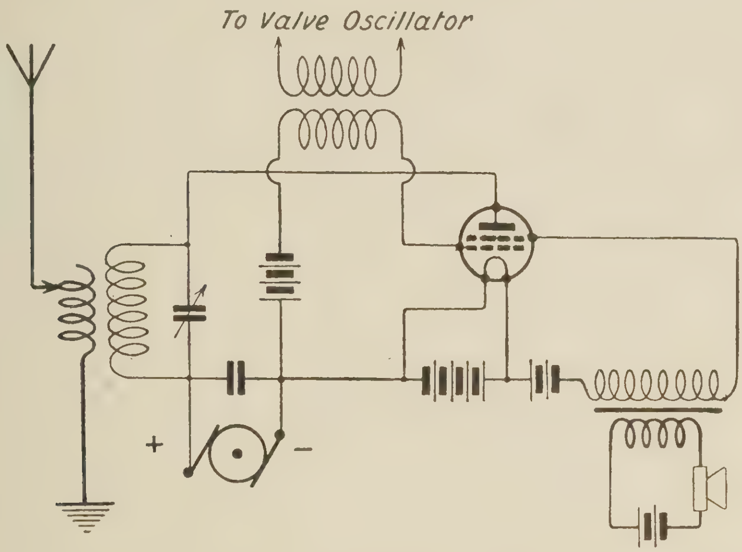


FIG. 145. In this circuit, the four-electrode valve functions as amplifier and as the microphone control valve.

The Negatron, which is due to **John Scott-Taggart,** has two anodes, as shown in Fig. 147, which gives a negatron circuit for the production of continuous oscillations.

A is the main anode, and A_1 the diversion anode. The valve is operated at saturation point, and when this has been arrived at by suitable adjustment of filament temperature and H.T. supply, the valve will oscillate over a wide range of frequencies determined by the constants of the circuit L_1C_1.

The action of the valve is due to negative resistance effects. If the normal grid potential is zero, the electrons from the filament divide themselves between the two anodes. When the potential of main anode A is increased, the potential of the grid is also raised. Consequently, the main plate will be robbed of a portion of its electron supply, owing to an increased number of electrons going over to the diversion anode A_1.

The actual effect of an increase of potential on the main anode, therefore, is to produce a diminution in the current in the main anode circuit, *i.e.* to produce a negative resistance effect.

Five-electrode Valve of the Marconi Company. (986)*—In 1919 the Marconi Company patented a method of producing oscillations by means of a thermionic valve, having one filament, two grids, and two plates.

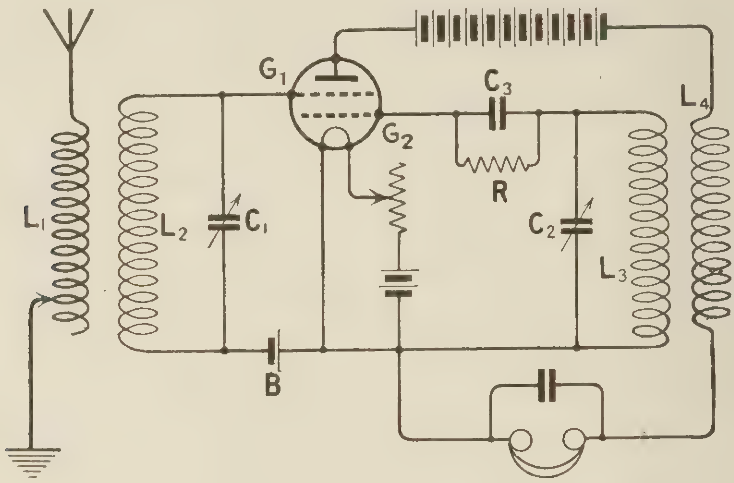


Fig. 145a. A feature of this four-electrode valve circuit is that for C. W. reception the grid circuit L_2 C_1 is tuned accurately to signal frequency.

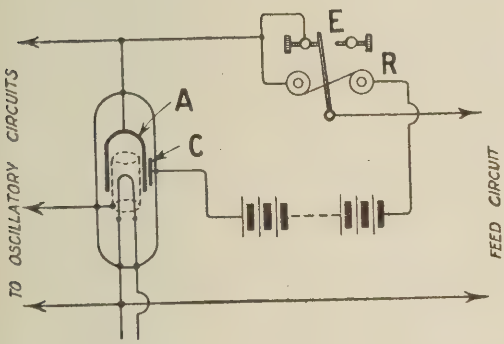
Q. A. Brackett's Five-electrode Valve (1000).—The 1919 patents covering this valve have been assigned to the Metropolitan-Vickers Company. Fig. 148 illustrates its functions. A steady electron stream takes place between filament F and plate P, through the telephones T.

The second filament, F_1, and the electrodes, P_1 and P_2, are connected respectively to the middle and ends of inductance L. When oscillations are being received, a continuous rectified current passes between F_1 and P_1, P_2, in the form of an electron stream from the filament. This interferes with the electron stream between F and P, and so controls the current in the telephone circuit.

Six-electrode Valve (996).—In 1913 **E. F. W. Alexanderson** invented a method of amplifying both half-waves of an oscillation by means of a valve having two plates, one filament, two grids, and an additional electrode kept at a positive potential to prevent static reaction between the two grids.

* See also **Lee De Forest's** five-electrode valve, patented in 1915—Ref. (1003); also (993).

DULL EMITTER VALVES (532), (533), (1014 to 1017).—The object of these valves is to obtain an increased emission of electrons from the filament, and so effect an economy in the current required to heat it. An alternative method is to reduce the gauge of the filament ; but there is a limit to this, and these filaments are very fragile, and have only very short lives. This latter method, therefore, has not found much favour.



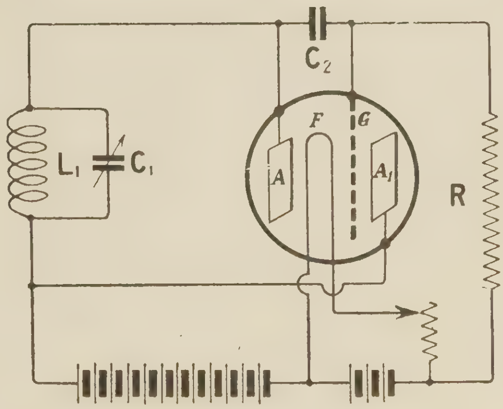


FIG. 146 (left). The fourth electrode in this valve, in conjunction with the relay, is used to prevent overheating of the anode.

FIG. 147 (right). A Negatron circuit for the production of continuous oscillations. As an alternative arrangement, the grid condenser C_2 and gridleak R may be dispensed with and a suitable grid battery connected in place of C_2 with its negative pole to the grid.

VON LIEBEN.—In 1911 **Von Lieben**, as previously stated, coated the filament of his valve with calcium or barium oxide.* In America, platinum filaments, or filaments made of platinum alloy, coated with a mixture containing oxides of calcium, strontium, barium, etc., have been employed with considerable success. It is only necessary to heat the filament of these valves to a dull red heat in order to obtain a free emission of electrons.

COOLIDGE (1014).—In 1911 **W. D. Coolidge** patented the employment of thorium oxide in the preparation of tungsten filaments.

LANGMUIR. (1015).—The following is a description of a dull emitter filament developed in America by **Dr. Langmuir** in 1914.

This filament is made of tungsten, to which has been added about 1 per cent. of thorium. After special heat treatment, it is claimed that the electron emission is increased as much

* **Wehnelt** had already shown the effect of a lime-coated filament in 1904 in another connection (1016).

T

as one hundred thousand times that of a piece of tungsten filament at the same temperature (532). By the employment of these thoriated filaments, therefore, a much lower temperature is necessary, and not only is a great saving of current effected, but at the same time the life of the filament is nearly doubled.

During the last two or three years many improvements have taken place in the manufacture of this type of filament, which is used in numerous examples of dull emitter valves now on the market.

THE GENERAL ELECTRIC COMPANY.—The General Electric Company have also carried out much research work on dull emitter valves. See the work of Thompson and Bartlett (1017).

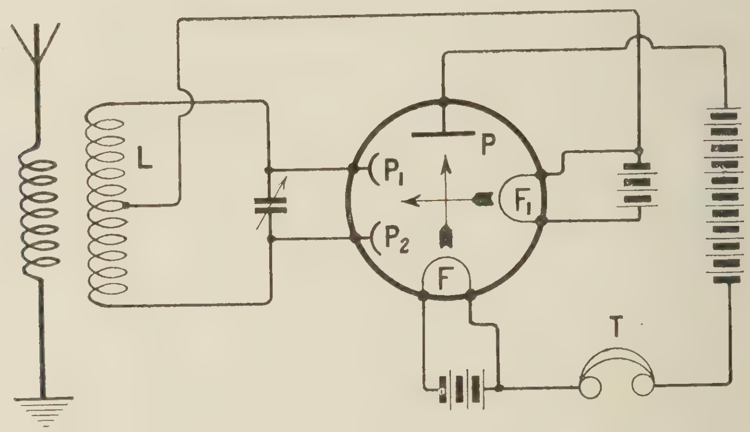


FIG. 148. Brackett's detector circuit employing a five-electrode valve having two filaments.

WESTERN ELECTRIC COMPANY (227).—In America, this company produced a valve in which the grid and filament are arranged so as to be in extremely close proximity, and the anode is also placed as near as possible to the grid, so that it will work on extremely low plate voltages.

In these valves the filament is wound over the grid, so that the latter is not in the space between the plate and the filament.

The grid is in the form of a wire loop, coated with an insulating layer of nickelous oxide, and the filament is wound round it. The plate is a sheet of metal at each side of and very close to the grid and filament.

The Western Electric Company also make a valve of this type for transmitting. In this case, a glass tube runs through the centre of the valve for purposes of water-cooling. The grid takes the form of a cylinder of metal, over which the filament is wound, and this is again surrounded with a cylindrical plate.

THE "THERMION" VACUUMLESS VALVE.—**E. V. Myers** in America (1101 and 1102) has recently invented a valve, illustrated in Fig. 149, which operates in air at ordinary atmospheric pressure. It has no glass bulb, but merely a removable perforated cover which is only intended to protect it from dust and draught. The special filament is ·035in. in

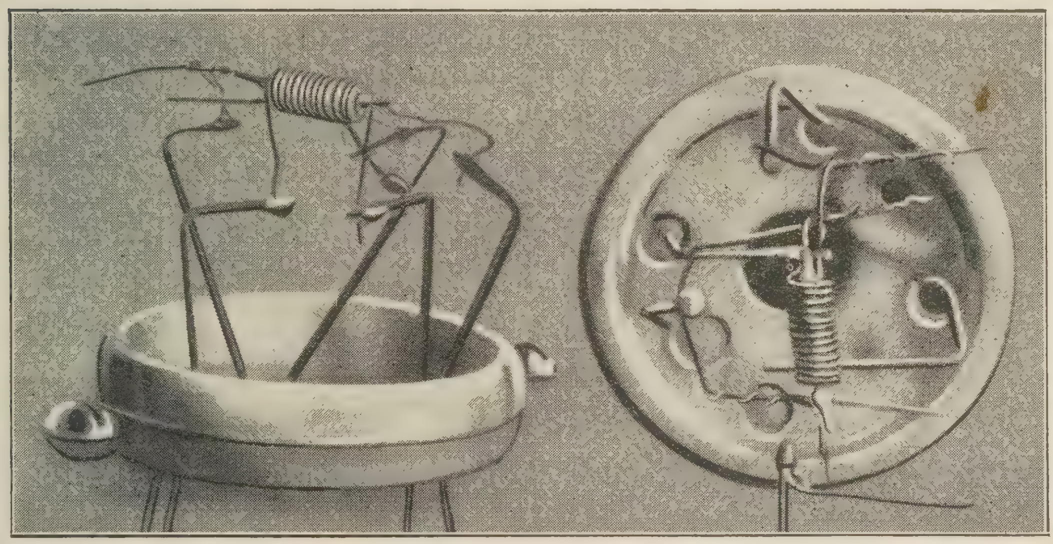


FIG. 149. The "Thermion" vacuumless valve with the dust cover removed, so as to show the arrangement of the electrodes.

diameter and operates on 110 volt lighting mains at about $\frac{1}{2}$ ampere. In use the filament temperature is about 800 degrees centigrade.

THE PHOTOTRON.—This American valve is a type of photo-electric cell. Instead of relying for its electron supply from the usual heated filament it obtains an electronic emission from the surface of a plate coated with a photo-active alkali metal, such as potassium, under the action of light.

In appearance it is like an ordinary radio valve and is mounted upon an ordinary standard valve base.

DE FOREST'S ULTRAUDION CIRCUIT (490).* One of De Forest's earliest valve circuits is illustrated in Fig. 150. With this arrangement oscillations are set up in the tuned circuit L_2C_1, which is connected across the grid and the plate of the valve, and inductively coupled to the aerial coil L_1. C_2 is a variable grid condenser which also acts as a stopping condenser to prevent a high positive potential being applied to the grid. For C.W. reception the circuit L_2C_1, is slightly detuned from the frequency of the incoming oscillations so that beats of audible frequency are produced.

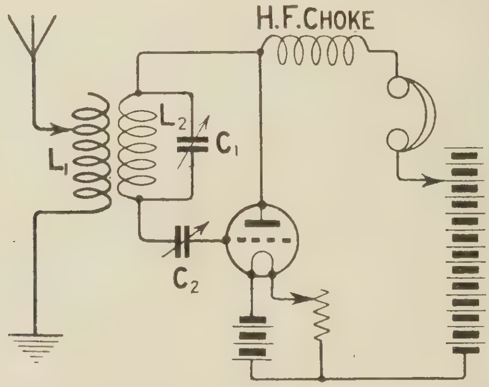


FIG. 150. De Forest's original Ultraudion circuit. It will be noted that no gridleak was employed with the soft Audion valve which he used.

THE DE FOREST REGENERATIVE OR FEEDBACK METHOD (1013), (600), (822), AND PATENT RIGHTS.—Several workers have laid claim to be the inventors of this method, and in the United States litigation proceeded for seven years over the matter. It commenced in March, 1917, when the **Westinghouse Company** (who then had control of the Armstrong patents) sued **Lee de Forest** for infringement. De Forest won, but further litigation took place between De Forest, Alexander Meissner, Irving Langmuir, and Edwin H. Armstrong. In the end, after the whole matter had been taken before the Columbia Court of Appeals, Lee de Forest was given control of the oscillating valve patents, and the so-called " feedback " circuit.

LEE DE FOREST'S ORIGINAL REGENERATIVE CIRCUIT (1013).—Fig. 151 is a reproduction of a sketch of the oscillation circuit as drawn by Dr. Stone two years after De Forest first con-

* For modified ultraudion circuits see Ref. (772). Many other circuits are to be found in Refs. (478) and (479).

ceived the idea. This played an important part in the litigation which took place subsequently over the reaction patents.

E. H. ARMSTRONG (481), (478), (521), (522), (604 to 607).—Between 1913 and 1923 **E. H. Armstrong** contributed a number of very important papers to the American Institution of Radio Engineers.

Armstrong filed the patent for his " Regenerative " circuit in October, 1913. On January 31st of that same year he had previously had his diagrams witnessed officially by a notary. At this date he was about 22 years of age.

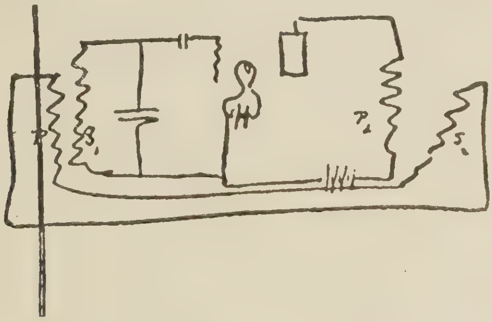


FIG. 151 is a reproduction of Dr. Stone's sketch of De Forest's reaction circuit.

A. MEISSNER (605).—**A. Meissner*** made four German patent applications in 1913 ; these are now embodied in his German patent 291604, of June 23rd, 1919 (605), which covers a regenerative circuit for the production of oscillations by means of a valve for transmitting purposes.

ROUND'S AUTO-DYNE, OR AUTO-HETERODYNE METHOD.—**H. J. Round's** patent No. 28413 of 1913 already referred to is of fundamental importance not only in so far as it relates to valve construction but also in regard to methods of employing three electrode valves for reception.

Fig. 152 is taken from the drawings accompanying the patent. Fig. 152A represents an arrangement for self-heterodyning, usually spoken of as the Auto-dyne or Auto-Heterodyne method.†

* Reference should be made to the 1914 British patent in the names of **Graf. G. von Arco** and **A. Meissner** (1012), which covers a "feed-back" method for reception, or for production of oscillations.

† See also the **Lieben** circuit, in which the aerial is coupled to the plate circuit—Ref. (772). Also **De Forest's** ultraudion.

The grid circuit L_1C_1 is inductively coupled to the aerial and tuned to the incoming wave, while the plate circuit L_2C_2 is inductively coupled to the grid circuit, and tuned to a slightly higher or slightly lower frequency. By choosing suitable coupling between these two circuits the valve will generate oscillations of the latter frequency and " beat notes " of audible frequency can be produced and heard in the telephones.

Fig. 152B.—This is another arrangement, usually known as the No. 16 circuit. In this circuit the valve is employed as a high-frequency amplifier, and the rectification is by means of a carborundum crystal and potentiometer.

Fig. 152C.—This arrangement shows inductive coupling to the aerial. In the plate circuit there is a choke coil L_3, in parallel with a variable condenser C_1. It will be seen that

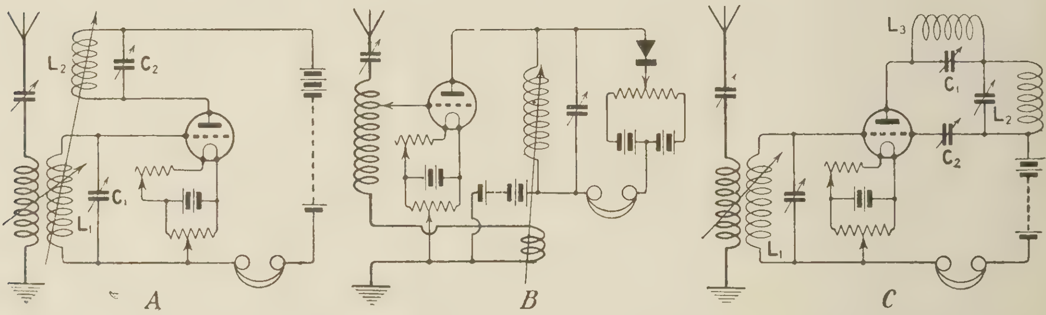


FIG. 152 shows three important circuits embodied in H. J. Round's Patent No. 28413 of 1913.

inductances L_1 and L_2 are not magnetically coupled in this case. According to the patent, C_2 is a condenser connected to the grid, which it is sometimes desirable to insert, to negative the effect of the capacity between the plate and the grid.

R. A. WEAGANT'S REACTION CIRCUIT. (456).—Fig. 153 shows a regenerative (or reaction) circuit, due to **Roy A. Weagant.** The special feature of the circuit lies in the method of introducing and controlling reaction which is effected by choosing a suitable coupling between L and L_1, and adjustment of the condenser C. An application of this method is found in the now well-known Reinartz reaction circuit.

ARMSTRONG'S SUPER-REGENERATIVE CIRCUITS* (481), (478), (521), (522), (604 to 607).—The following notes are extracted

* For **Flewelling's** Super-regenerative Circuit see later.

from **E. H. Armstrong's** paper before the Institute of Radio Engineers in 1922 (521). He refers to the pioneer work of **Turner*** as leading directly towards the development of his own " super-regenerative " system, and he also refers to the work of **Bolitho** as follows :

" Bolitho† contributed an important improvement, by replacing the mechanical relay of Turner, which operated only upon the reception of a signal, by a valve relay which was continuously operated by independent means (748).

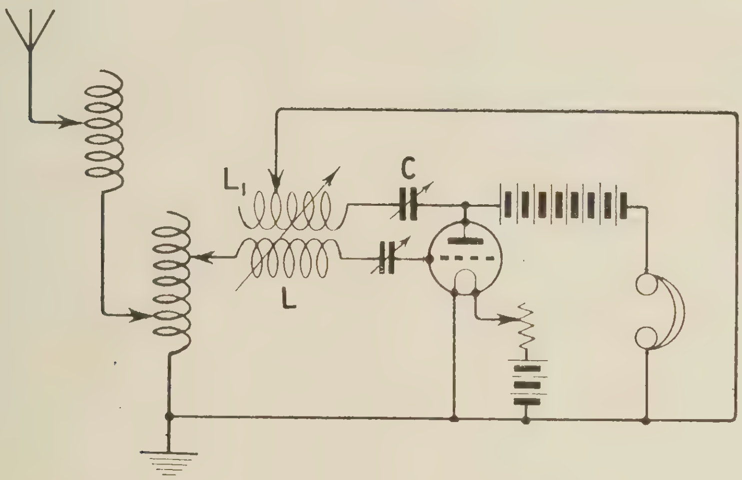


FIG. 153. A circuit due to Roy A. Weagant, in which reaction is controlled by adjustment of the condenser C.

Briefly, this was accomplished by connecting a second valve to the oscillating circuit of Turner's arrangement, with a reversed feed-back (reaction) connection, and supplying the plate circuit of the second valve with an alternating current. When the " threshold " value of the first tube was overcome, and a free oscillation started in the system, the reversed " feed-back " of the second tube comes into action, and at that time, when the voltage supplied to the plate is positive, damps out the free oscillation and permits the grid of the first tube to return below the "threshold" value. This represents the second step in the utilization of the free oscillation for the production of amplification."

Armstrong's scheme‡ provides a method by which full use of reaction can be made without setting the valve into a state of self-oscillation.

* For **Turner's** Valve Relay see pages 267 and 268.

† **Bolitho's** patent No. 156330/19.

‡ U.S. patent 1113149, 1914 (604).

The employment of reaction may be considered as the insertion of negative resistance into the valve circuits. As the reaction becomes more and more effective, it reduces the positive resistance of the circuits until the two resistances balance, and the valve begins to generate oscillations. Given such a condition of affairs, Armstrong has shown that the state of oscillation can be controlled by superimposing H.F. oscillations on the oscillatory circuits, which we desire to check. Matters can be so arranged that the circuits will oscillate during alternate half-cycles of the superimposed oscillations, which will thus act like a switch on the first circuit, " short circuiting " it once during each oscillation, and, so long as these interruptions are sufficiently rapid, they will

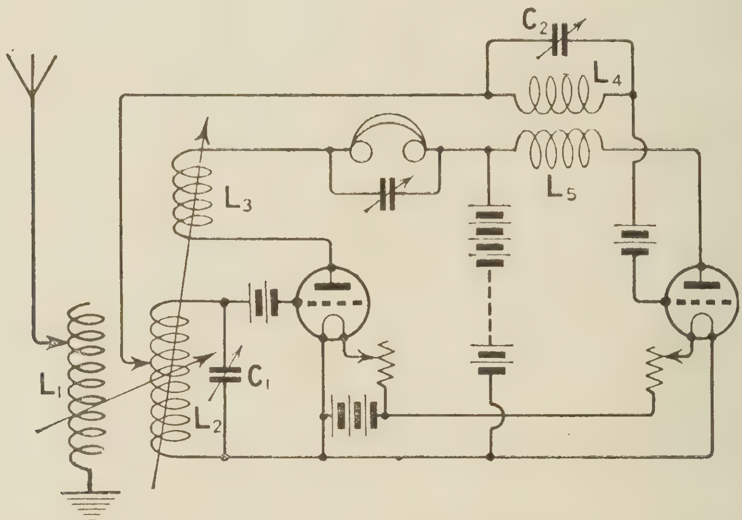


FIG. 154A shows one of Armstrong's super-regenerative circuits in which a second valve is employed to produce the quenching oscillations.

produce no sound in the telephones. This method is specially adapted to the reception of short waves, as the amplifying power of the system increases inversely as the square of the wavelength (511–515).

Fig. 154A shows one Armstrong circuit, in which the first valve acts as a detector,* with reaction coupling between plate and grid circuits, and the second valve acts as oscillator, the coil L_4 in its grid circuit being tuned by C_2 to a suitable quenching frequency and coupled to L_5 to produce the desired oscillations. Part of the coil L_2 is common to the grid circuits of both the detector and the quenching valve, so that when the circuit is suitably adjusted the oscillation of the detector

* Hard valves are necessary for super-regeneration.

valve is periodically interrupted, thus giving the super-regenerative effect.

Fig. 154B represents a single valve "Armstrong" super-regenerative arrangement for use with a frame aerial.

The reaction coupling between L_1 and L_2 requires critical adjustment. The quenching coils L_3 and L_4 may have inductances equivalent to Nos. 1500 and 1250 of the plug-in type of coil, and are shunted by condensers C_3 and C_4 of the order of ·005 μF. The grid condenser C_2 is of conventional

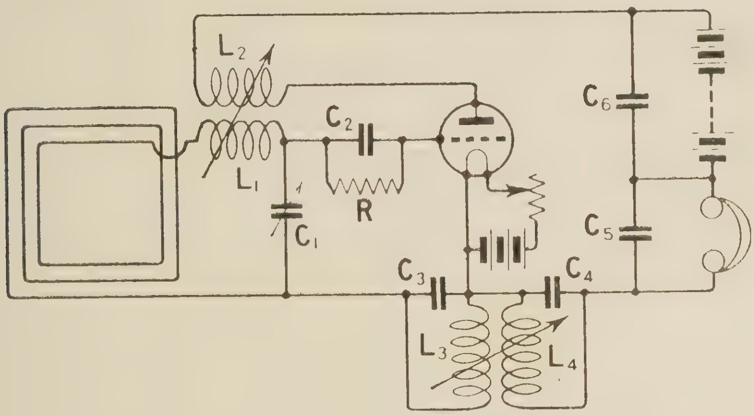


FIG. 154B. A single-valve Armstrong super-regenerative circuit for use with a frame aerial.

value (·0002 or ·0003 μF) but a low value, $\frac{1}{2}$ or 1 megohm, has been found preferable for the gridleak R. The high-pitched whistle in the telephones due to the quenching oscillations is to some extent reduced by the provision of a large telephone condenser C_5 of ·005 μF.

ARMSTRONG'S TUNED PLATE CIRCUIT (478).—In the course of a lecture given in 1915 before the Institute of Radio Engineers at New York, **E. H. Armstrong** described his tuned plate circuit which is shown in Fig. 155A. He showed that by tuning the plate circuit by means of an inductance L wound to a suitable value and preferably shunted by a variable condenser C, the valve could be made to oscillate when this circuit was brought into resonance with the tuned grid circuit. In his lecture Armstrong pointed out that the regenerative coupling was provided mainly through the capacity of the valve.

J. F. Johnston's Tuned Cathode Circuit (833), (835).—With the object of stabilising* high-frequency amplifiers, **Johnston** tuned the plate circuit on the cathode side, *i.e.* he placed the tuned circuit (consisting of an inductance and condenser in parallel) between the negative side of the H.T. battery and its connection to the filament of the valve. In order to make the set oscillate a reaction coil was necessary.

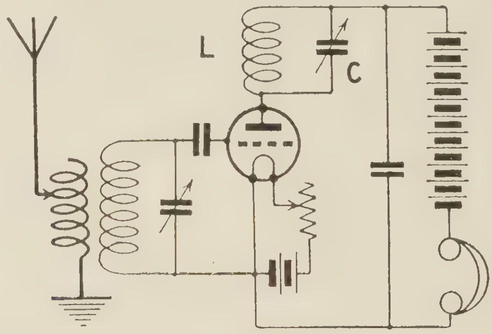


Fig. 155a. In Armstrong's tuned-plate circuit the "feed back" is provided by the grid to plate capacity of the valve.

Armstrong's Combined Audio and Radio Frequency Regenerative Method (822), (456).—Fig. 155B shows one of Armstrong's reaction circuits for which he claimed one hundred fold amplification of weak signals. The anode circuit is tuned by an adjustable coil L_3 and the coil L_1 is coupled to L_2 to utilise the radio-frequency component in the anode circuit to produce reaction. By means of an iron core transformer $T_1 T_2$ connected as shown, and having its windings tuned to the correct audio-frequency, it is stated that an audio-frequency reaction effect may also be obtained.

The circuit, however, requires critical adjustment to maintain it in a stable condition when the maximum amplification is sought.

Armstrong's Electro-static Grid-plate Coupling.—Armstrong also showed methods in which the plate and grid circuits were electro-statically coupled.

Hard Valve Characteristics and Circuits.—On March 3rd, 1915, Armstrong read a paper on "Hard Valve Characteristics and Circuits," before the American Institute of Radio

* In 1923 **C. F. Phillips** (see "Journal of the R.S.G.B.") described a method of stabilising, by placing a non-inductive resistance in the plate circuit between the plate of the valve and the tuned circuit. This resistance consists of a single layer of fine insulated resistance wire, wound round a small copper or brass cylinder.

Engineers. This was a most exhaustive explanation of the phenomena of valve rectification, high and low frequency amplification, and oscillation generation, and the explanations he then gave in the main hold good.

THE TURNER VALVE RELAY (523), (524), (525)*—Fig. 156 illustrates one arrangement of **L. B. Turner's** valve relay.

Turner was the first to make use of free oscillation in a regenerative system of amplification. The grid bias is so adjusted as to prevent the valve from oscillating.

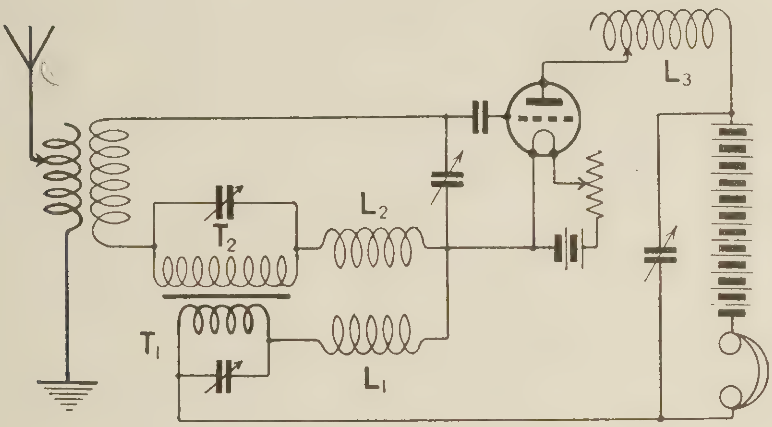


FIG. 155B. shows a circuit attributed to Armstrong, for which a double reaction effect is claimed.

The effect of a signal is to increase the grid potential, and bring it just past threshold value, and allow the valve to commence to oscillate, with consequent change of the mean plate current. This current change operates the relay and causes it to short circuit the reaction coil L. Reaction ceases, and the potential of the grid drops back again below the threshold value.

THE FLEWELLING SUPER-REGENERATIVE CIRCUIT (516), (512), (810), (813 to 816).—Since the introduction of the super-regenerative circuits by Armstrong, several other super-regenerative methods have been proposed, notably that due to **E. T. Flewelling** whose circuit is shown in Fig. 157. As in the case of the Armstrong method (already described), the valve is first caused to oscillate. Its oscillations are then quenched by means of condenser discharge ripples acting on the grid of the valve.

* Some thermionic tube circuits for relaying and measuring, given in a paper by **Dr. Eccles** and **Miss Leyshon** at the Institution of Electrical Engineers in 1921—see Ref. (770)—should also be referred to.

This circuit presents considerable difficulty in working. The two variable resistances, R and R_1, require very careful and critical adjustment as does the coupling between L_1 and L_2.

G. G. BLAKE'S FLAME GRID LEAK* (810).—The **Author** has shown one method of overcoming this difficulty by employing air ionized by means of two flames, in place of the usual variable high resistances.

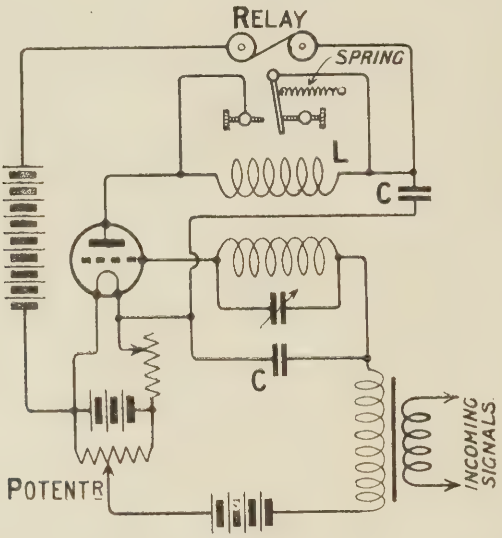


FIG. 156 illustrates one arrangement of L. B. Turner's oscillating valve relay. The condensers marked C are high-frequency by-pass condensers.

The main feature is the simultaneous control of both these resistances. This is achieved in the following manner :

Both flames are fed from one supply pipe and the gas supply is reduced until there is only sufficient pressure to burn each flame at half strength. If one flame is then turned down, the other flame is increased proportionately.

The usual Flewelling circuit is employed, and in each case the burner is connected to one side of the condenser, its other side being connected to a small spiral of wire suspended well above the flame.

Signals received with a Flewelling circuit are very strong, but the quenching of the self-oscillation of the valve produces an objectionable whistle which is in evidence all the while. It is comparable to the droning note of "bagpipes," only it is far more shrill.

* See also Ref. (1106) for **Author's** method employing selenium grid leaks controlled by light for Flewelling and other circuits.

E. T. Flewelling's Simplified Super-circuit.—**Flewelling** showed subsequently (see notes from his letter in "Wireless Weekly," July 25th, 1923, also Ref. 815) that the second adjustable high resistance could be dispensed with, together with two out of the three 0·006 μF condensers shown in Fig. 157. The connections are then as follows :

The condenser marked C is retained in the grid circuit and the wire X leading from the positive side of the high-tension battery is connected to the side of condenser C remote from the filament. The above arrangement can be

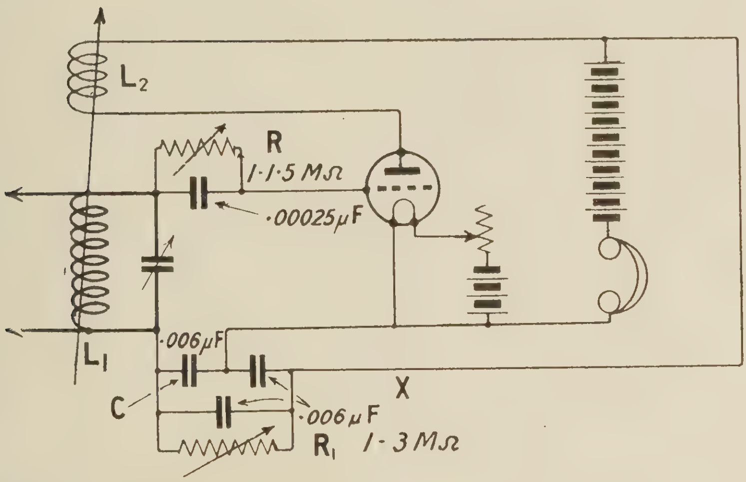


Fig. 157. The Flewelling super-regenerative circuit. For the simplified version described in the text a higher value is usually required for the gridleak R.

employed with an outside aerial, a frame aerial, or without any aerial. In the last case, the earth is connected to the grid end of the tuning inductance.

The Blake-Flewelling Circuit (810), (816).—This circuit was described by the **Author** in 1924. The general arrangement is depicted in Fig. 158. from which it will be seen that it is based upon the Flewelling circuit ; it has, however, one or two unique features.

(1) If the reaction coil L_2 is large and closely coupled to the tuning inductance L_1, the set functions in the true Flewelling manner, and gives loud signals, accompanied by the usual "whistle."

(2) If, however, a relatively small reaction coil is chosen, the set can be adjusted permanently with coils L_1 and L_2 set at a fixed position at a point just before the valve breaks into self-oscillation, with only a small proportion of the capacity

of C_1 in use. The amount of reaction can now be very perfectly and gradually controlled by means of small variations of the variable condenser C_1.

Another variable condenser C_2 is used for tuning. A flame grid-leak is employed as shown. The flame F passes through the centre of a small metal cylinder, or wire spiral P, without actually touching it, or the metal spiral S above it. The grid condenser C_3 is of conventional value, and C_4 may be ·006 μF.

Adjustment of either the size or position of this gas or spirit flame gives good grid-leak adjustment.*

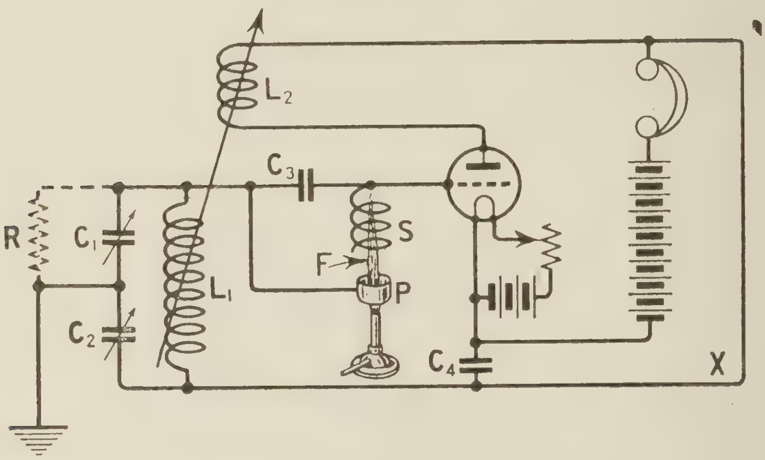


FIG. 158. A modification of the Flewelling circuit due to the Author.

When employed in the second manner above described the set no longer functions as a Flewelling Super-circuit. The connection X from the positive side of the high-tension battery to the grid circuit causes the valve to function near to the top of its characteristic curve. If the grid-leak and other adjustments are carefully made, most of the broadcasting stations can be picked up without the employment of any outside aerial. In order to avoid capacity effects from the operator's body as much as possible, a non-inductive high resistance may be inserted across condenser C_1 as shown by dotted line R.

THE ULTRA - HETERODYNE OR SEPARATE HETERODYNE METHOD (480).—An American patent for this method was taken out by **Fessenden** in 1913 (see also Chapters VI. and XIV. of this book for his earlier heterodyne methods).

* The **Author** has also employed radio-active spirals or plates to ionize the air and form grid-leaks—Ref. (810).

Fig. 159 illustrates the method employed. This arrangement has several decided advantages over the Autodyne method :

(1) In the latter the receiver circuit must be slightly mistuned from the received waves in order to obtain beat notes ; whereas when a separate oscillator is employed to supply the slightly detuned wave, the aerial and receiving circuits can be sharply tuned.

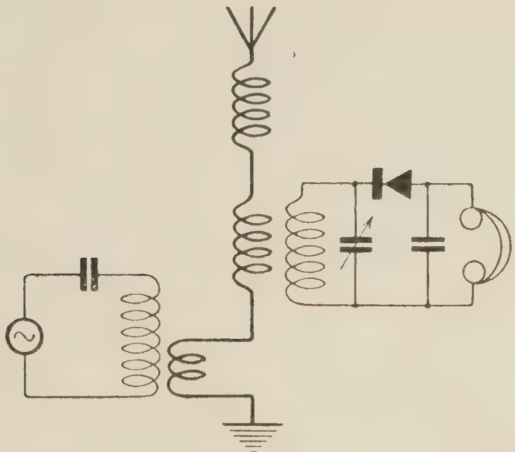


FIG. 159. Illustrates the principle of the separate heterodyne method of reception.

(2) When using a separate Heterodyne, looser coupling can be employed for the circuits, and the tuning made sharper with consequent reduction of jamming from unwanted stations.

HOMODYNE RECEPTION (825).—There are several circuit arrangements by which homodyne reception can be achieved. The principle of the method, as adapted for the reception of telephony, consists in using an oscillating valve circuit which is coupled to the aerial circuit tuned to the incoming oscillations. The frequency of the local oscillations is made exactly equal to the frequency of the carrier wave of the incoming signals. If the carrier wave is modulated, then when this condition obtains, signals corresponding to the modulation will be audible in the telephones included in the anode circuit of the oscillating valve.

The advantages of the method lie in the fact that the effective carrier oscillations are increased in amplitude by the addition of the local oscillations, and since the response of the detector valve obeys a square law, the total response is considerably increased.

Certain precautions are, however, necessary for the successful practical application of the principle. It is essential in order to avoid distortion that the carrier wave frequency and the frequency of the local oscillations should remain very constant when the final adjustments have been made. It has been found desirable in practice to aim at having the incoming oscillations as strong as possible and the local oscillations comparatively weak; this also minimises to some extent the possibility of serious radiation from the aerial.

When the incoming oscillations are weak, preliminary high-frequency amplification may be necessary to obtain the condition described above.

THE REFLEX OR DUAL CIRCUIT (545), (551 to 553), (560), (830), (883), (884), (911 to 920), (1005); W. P. THOMPSON.—**W. P. Thompson** described a dual amplification circuit in a 1913 patent.*

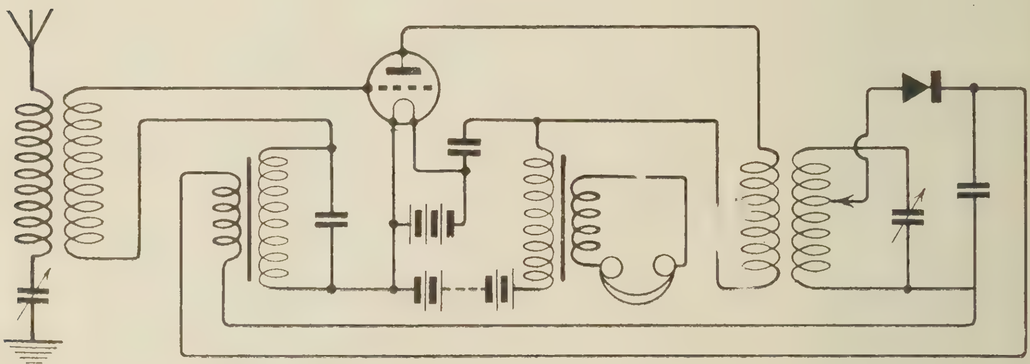


FIG. 160. The dual amplification circuit given in British patent No. 8821 of 1913.

This is illustrated in Fig. 160, which is taken from this specification.

Marius Latour.—In France a reflex circuit was developed and patented by **Latour** (545).

W. H. ECCLES AND F. W. JORDON (920).—In 1920 **Eccles** and **Jordon** contributed an article to "The Electrician" dealing with note magnification with a high-frequency amplifier.

C. L. FORTESCUE (1038).—**Fortescue** gave an important paper on "The Design of Multi-stage Amplifiers," at the Institution of Electrical Engineers, in 1920.

* Fig. No. 2 of this same patent specification (911) covers the employment of one stage H.F. valve amplification, followed by detection followed by L.F. valve amplification. **Latour** (1004) has a British patent of 1916, covering the employment of iron-cored transformers in a similar series of stages of amplification.

JOHN SCOTT-TAGGART (918).*—Probably one of the best known reflex circuits in this country is that developed by **Scott-Taggart**, and known as the S.T.100. It was described by him in "Modern Wireless" in 1923 (918).

The original S.T.100 circuit is shown in Fig. 161. The circuit was afterwards further developed by Scott-Taggart. See Refs. (553), (830), and (919).

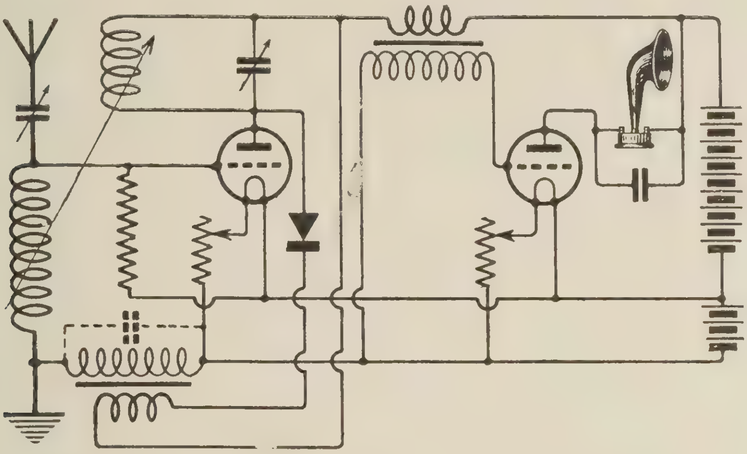


FIG. 161 shows the original S. T. 100 Circuit. Various improved forms have been developed since this circuit was first described in 1923.

The RESISTOFLEX CIRCUIT (1075).—In 1924 **John Scott-Taggart** published the circuit shown in Fig. 161A. The main feature of this reflex method is that the audio-frequency currents from the detector valve V_2 are fed through a high resistance R, the potentials across R being applied to the grid of the high-frequency amplifying valve V_1, which functions as the dual valve. This method obviates the employment of a low-frequency transformer, thereby reducing to some extent the tendency to low-frequency buzzing with consequent distortion, which is often a source of trouble in some other forms of reflex circuits.

AUDIO-FREQUENCY REACTION (559).—Fig. 162 shows an interesting circuit given by **Theaker,** in which use is made of a special intervalve audio-frequency transformer having three windings. The inner two are wound with a 1 to 1 ratio, while the outer or reaction winding has about half the number of turns.

* For a useful paper on the theory of reflex wireless receivers see **Scott-Taggart** —Ref. (1005).

RESISTANCE-CAPACITY COUPLED AMPLIFIERS (456), (227), (562 to 564), (671).—In France, during the War, the Wireless Military Staff in Paris, under **General Ferrié**, developed the resistance-capacity coupled amplifier. Fig. 163 is typical of the earlier circuits employing resistance-capacity coupling. Potentials developed across the coupling resistance (R) are applied to the grid of the succeeding valve through a condenser (C) which also acts as a stopping condenser to prevent the application of a high positive potential to the grid by the

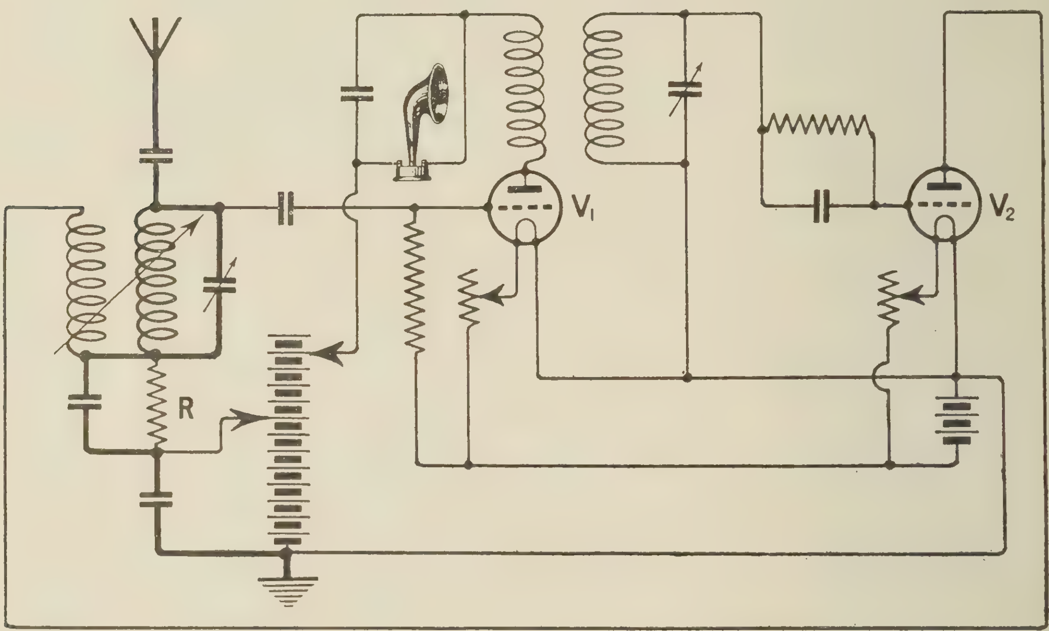


FIG. 161A. In the " Resistoflex " Circuit the usual reflex transformer is replaced by a high resistance R.

high-tension battery. The normal grid potential of V_1 is fixed at a suitable working value by means of the potentiometer P, while the steady potentials of the grids of V_2 and V_3 are adjusted by the provision of suitable gridleaks (R_1).

For C.W. reception a regenerative effect was obtained by adjustment of a variable condenser C_1 which could be connected between the plate of V_3 and the grid of V_1 by means of the switch S.

SUPERSONIC HETERODYNE, OR THE SUPER-HETERODYNE METHOD (1076 to 1080) and (774).*—This method was described in detail by **Armstrong** in a paper before the Institute

* See also **John Scott-Taggart's** use of frequency raisers for reception in Chapter XIV.—Refs. (444) and (651) ; also **Lucien Levy's** French patent, August 4th, 1917, and English patents—Ref. (774).

of Radio Engineers, New York, on Dec. 3rd, 1919 (1076). Briefly, using his own words, the method consists "in reducing the frequency of the incoming signal to some predetermined super-audible frequency which can be readily amplified, passing this current through an amplifier, and then detecting or rectifying the amplified current.

The transformation of the original radio-frequency to the predetermined value is best accomplished by means of the heterodyne and rectification."

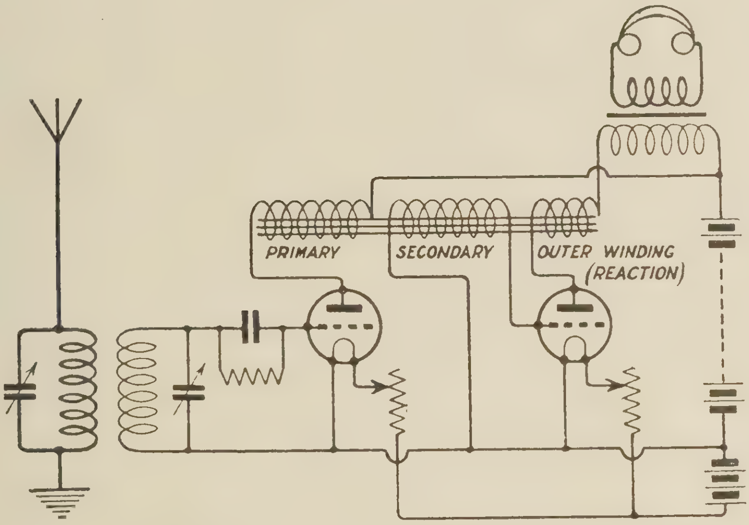


FIG. 162. A circuit described by Theaker employing a special low-frequency transformer to produce audio-frequency reaction effects.

A considerable amount of experimental work has been carried out with this method of reception. It is to be particularly recommended for use in conjunction with a frame aerial and while it involves the employment of several extra valves in order to obtain signals of normal audibility, it gives excellent results and is exceedingly selective.

Fig. 164A is a diagram illustrating the principles employed.

H. HOUCK'S SUPER-HETERODYNE CIRCUIT (1080).—In this circuit, shown in Fig. 164B, two tuned circuits are connected to the oscillator. Circuit L_1C_1 is tuned to the frequency of the incoming signal, while L_2C_2 is a regenerative circuit tuned to such a frequency that its second harmonic beats with the incoming frequency and produces a reduced frequency which is passed on to the amplifier.

THE TROPADYNE CIRCUIT (1081), (1082), (1083).—Fig. 164C shows a five-valve super-heterodyne circuit in which the first

valve functions as detector and oscillator using the " Tropadyne " method of connections, V_2 and V_3 are the intermediate frequency or long wave amplifiers, and V_4 is the second detector followed by a stage of low-frequency amplification V_5.

The circuits of V_1 include arrangements for producing the local oscillations by coupling the anode coil L_2 to the circuit L_1C_1 in the grid circuit of the valve. A grid condenser C and gridleak R are provided for rectification, one side of the grid condenser being connected to the electrical centre or nodal point of the coil L_1.

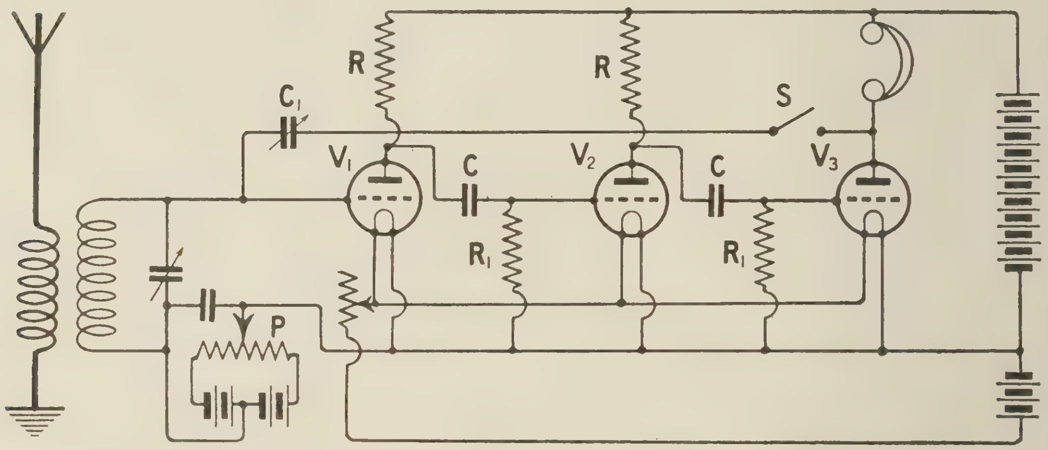


FIG. 163 is typical of the earlier circuits employing resistance-capacity amplification.

The frequency of the local oscillations is adjusted by means of C_1 so that these oscillations combine with the incoming oscillations to produce, after rectification, a beat frequency equal to that to which the long wave amplifier is tuned.

PUSH AND PULL AMPLIFIER (831), (1036).—Fig. 165 illustrates a method of low-frequency amplification designed to enable a large input to be amplified without distortion using ordinary small valves. Two valves of the same type are connected in parallel by means of two special transformers, the input transformer T_1 having a centre tap on the secondary winding connected to the negative of a common grid-bias battery B, while the output transformer T_2 has a centre tap on the primary connected to high-tension positive.

A current impulse in the primary of T_1 will set up a voltage in its secondary winding, and at an instant, say, when the

grid voltage of V_1 is increased, the grid voltage of V_2 is decreased. The anode current of V_1 will then be increased and the anode current of V_2 decreased. These current changes in the two halves of the primary winding of T_2 cause a voltage to be developed across the secondary and a current therefore flows in the secondary circuit through the loud-speaker.

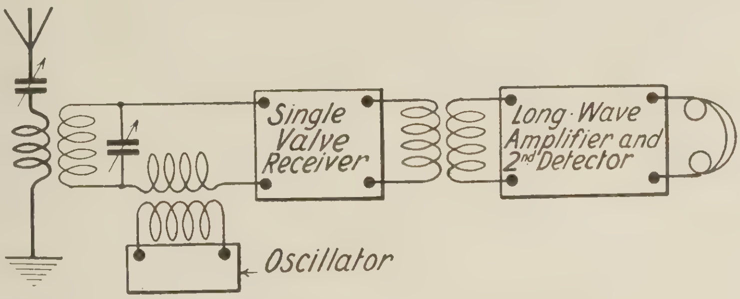


FIG. 164A. A schematic diagram illustrating the principles of super-heterodyne reception.

SCOTT-TAGGART'S GRID TO PLATE AMPLIFICATION METHOD (1001).—In 1919, **John Scott-Taggart** patented the circuit arrangement shown in Fig. 166. The anode of the first valve is connected to the grid of the second, and the anode of the second to the grid of the first. R is a variable high resistance ;

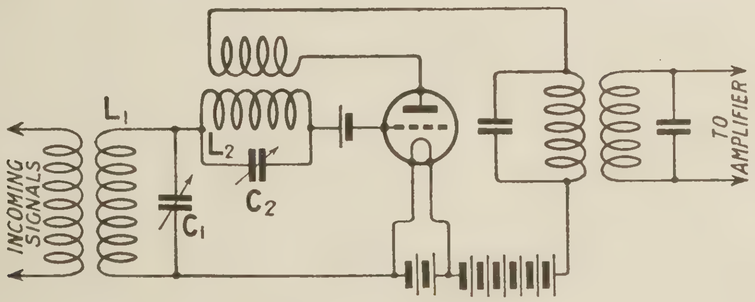


FIG. 164B shows the essential circuits of the oscillator and first detector valve of Houck's " second harmonic " method of super-heterodyne reception.

by suitable adjustment of the value of this an increase in the potential of the anode of the first valve may be made to produce a decrease in the anode current of that valve and vice-versa.

GRAHAM'S AND RICKETS' IMPEDANCE-COUPLED POWER AMPLIFIER (1018).—In 1924 **E. A. Graham** and **W. J. Rickets** patented the method of amplification shown in Fig. 167. The plate of

the first valve is connected to the positive side of the high-tension battery through an iron core choke Z, and to a coupling condenser C, the other side of which is connected to a tapping on the auto-transformer Z_1 in the grid circuit of the second valve.

H. J. ROUND'S NEUTRALIZATION OF GRID TO PLATE CAPACITY (534), (535), (225).—Reference has already been made (see Fig. 152C) to **H. J. Round's** patent No. 28413 of 1913. One of the clauses in this patent specification reads as

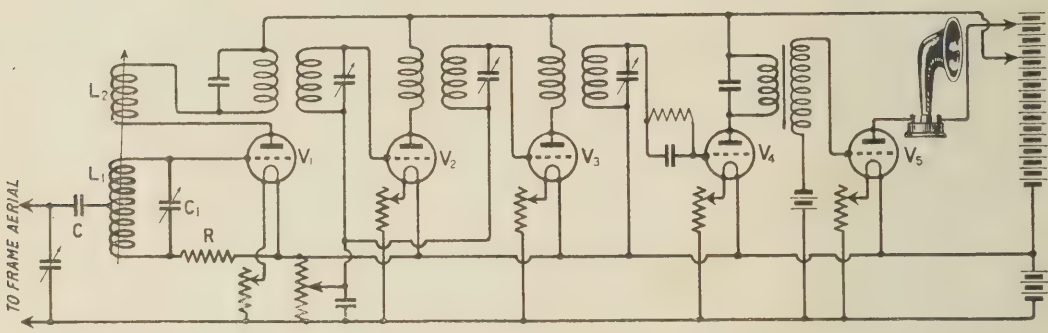


FIG. 164C. A five-valve "Tropadyne" super-heterodyne circuit.

follows : "J is a condenser connected to the grid, which it is sometimes desirable to insert, to negative the effect of the capacity between the plate and grid." ($J = C_2$, Fig. 152C).

This was probably the first time that the possibility of balancing out the internal capacity of a valve was suggested.

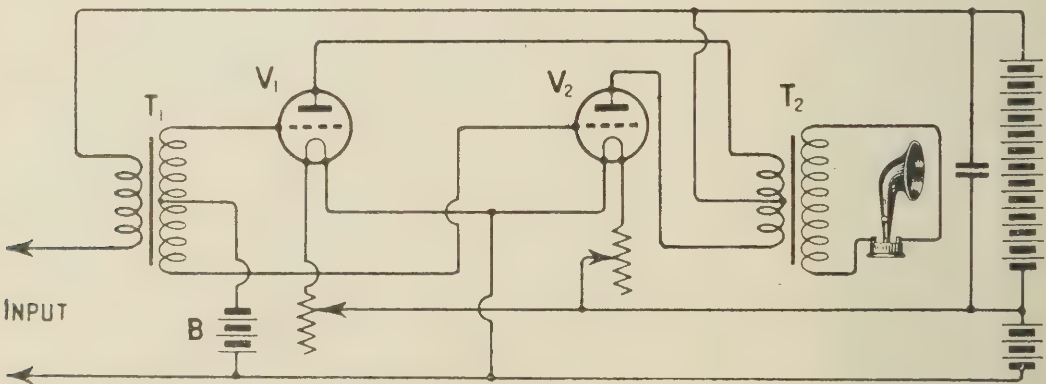


FIG. 165. The "push-pull" method of L. F. amplification enables small valves to amplify a large input.

C. H. WRIGHT'S NEUTRALIZATION METHOD.—Two years later, in 1915, **G. M. Wright**, in his British patent No. 8926, covering his "dimmed valve limiter," showed an electro-

magnetic method of balancing out the effects of capacity between the grid and plate of a valve. This method is described later (see Fig. 174B).

HAZELTINE'S NEUTRODYNE CIRCUIT (534), (535), and (225).—On March 2nd, 1923, **Louis A. Hazeltine** described his neutrodyne circuit before the Radio Club of America, at Columbia University, New York, under the title: "Tuned Radio-frequency Amplification with neutralization of capacity coupling."

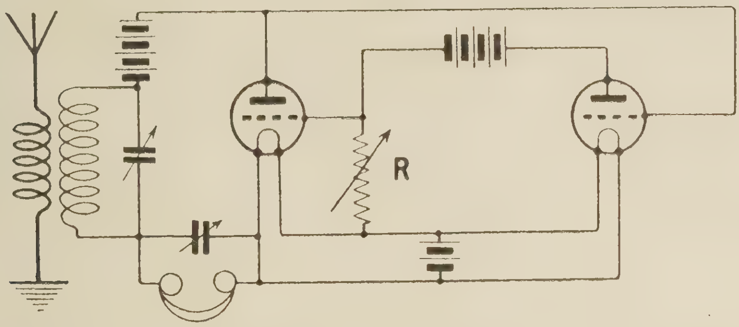


FIG. 166. A receiving circuit patented by John Scott-Taggart employing a combination of valves which may be adjusted to produce negative resistance effects.

This circuit provides a means of neutralizing the inherent self-capacity of a three-electrode valve, *i.e.* the capacity between its grid and plate which may form a capacity coupling between the grid and plate circuits of a valve, and is the frequent cause of self-oscillation in valve circuits. The

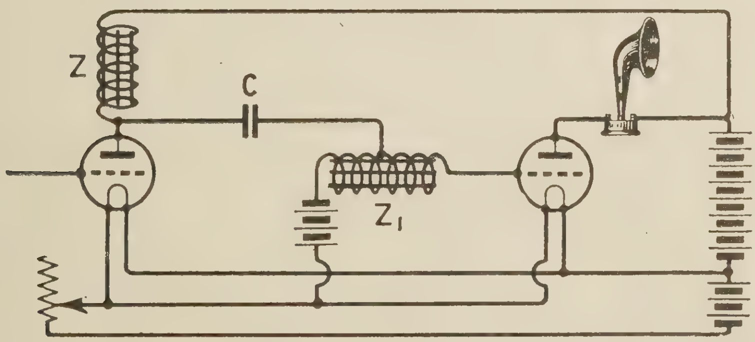


FIG. 167. The power amplifier circuit of Graham and Rickets.

method of overcoming self-oscillation in most general use hitherto was to alter the potential of the grid with respect to the filament by means of a potentiometer; but it had the serious drawback, that its employment tended to broaden the tuning and lessen the amount of amplification.

Stabilizers are sometimes employed to prevent self-oscillation. In some cases a resistance is placed in series with the anode tuning coil ; but while it may prevent self-oscillation, it causes considerable loss of sharpness in tuning.

The neutrodyne method has many advantages. The valves are incapable of oscillating, unless reaction is purposely employed. The tuning is much sharper than is possible where stabilizing devices are employed, and much greater amplification per valve is obtained.

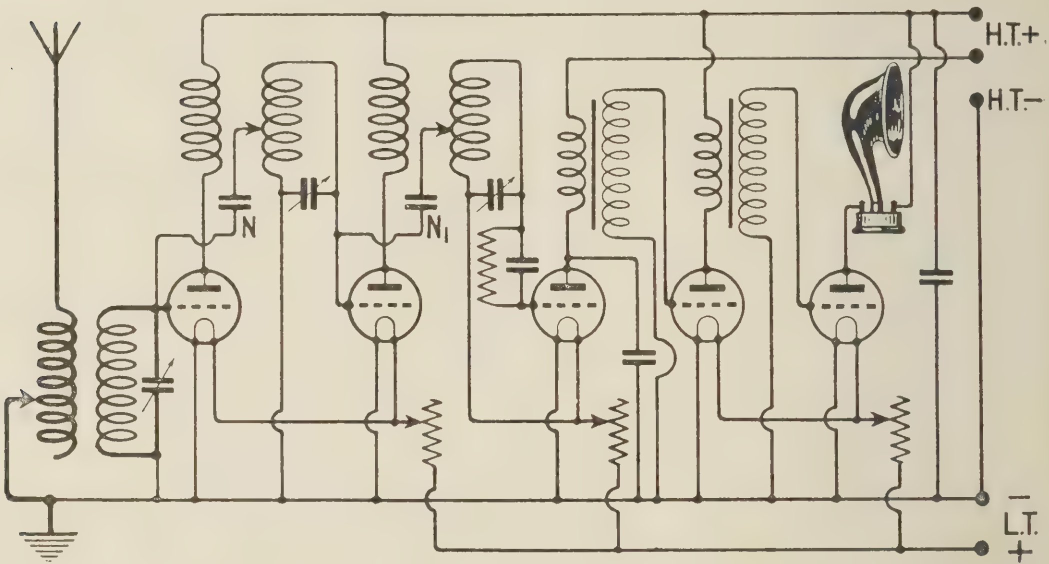


FIG. 168. A five-valve circuit due to Hazeltine, employing two stages of high frequency amplification, with neutralised capacity coupling.

Fig. 168 shows Hazeltine's neutrodyne connections for a five-valve circuit, comprising two H.F. stages neutrodyned, one detector, and two stages of note-magnification. N and N_1 show the neutralizing capacities.

UNIDYNE OR SOLODYNE RECEPTION WITH A FOUR-ELECTRODE VALVE (902), (903), (904).—This method was brought forward by **G. V. Dowding** and **K. D. Rogers** in 1924. The principle, as the name implies, is to operate a valve circuit with a " single power," *i.e.* one battery to supply both the high and low tension.

Their original idea was to obtain the high-tension supply by use of a step-up transformer in the anode circuit connected to a metal plate wrapped round the outside of the valve to act as a second plate. After obtaining moderate results

with this arrangement a valve with two grids was employed. This effectively reduced the internal resistance of the valve.*

It is, however, a matter of doubt in the author's mind if such powerful results are to be expected, when one endeavours to reduce the power available for working the set to an absolute minimum. It is somewhat analogous to watering a garden with a water-can when a hose is available.

"HIGH-TENSIONLESS" THREE-ELECTRODE VALVE CIRCUIT (905 to 908).—In 1924 **A. D. Cowper** described a "high-tensionless" circuit, using an ordinary three-electrode valve. This is illustrated in Fig. 169. The essential features are

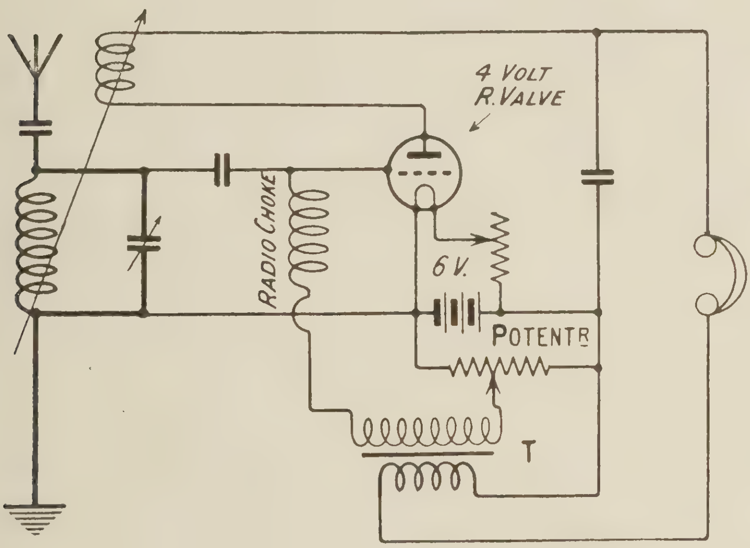


FIG. 169. A "high-tensionless" three-electrode valve circuit due to A. D. Cowper.

the radio choke, the transformer T, and the potentiometer which is used to control the audio-frequency reaction effect.

ELECTROLYTIC AMPLIFIERS (WITHOUT VALVES†), (747), (1031).—**Y. Neinhold**‡ has recently patented in Germany a new method of audio-frequency amplification. In place of a three-electrode valve a small container fitted with three electrodes and filled with a colloidal solution is employed.

* For full description and diagrams of the **Dowding-Rogers** method see Ref. (902).

† For another method of amplification without valves see **Brown's** microphone amplifier.

‡ **Roussel**, in France, has also carried out similar experiments with colloidal solutions (1031).

Fig. 170 shows the arrangement. The action appears to be due to a negative resistance effect. It is essential that the solution be in a colloidal state. It has also been claimed (1031) that colloidal solutions can be influenced by a magnetic field.

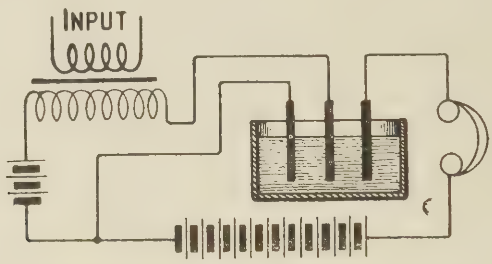


Fig. 170 shows the arrangement of Neinhold's electrolytic amplifier.

THE REINARTZ TUNER (517 to 519).—This tuner, invented by **John L. Reinartz,** was described in the June number of *Q.S.T.*, 1921.

The aerial circuit of this tuner functions "aperiodically" and remains on one adjustment over a band of wavelengths. The connections are shown in Fig. 171A. The grid circuit is sharply tuned by means of a variable condenser C_1.

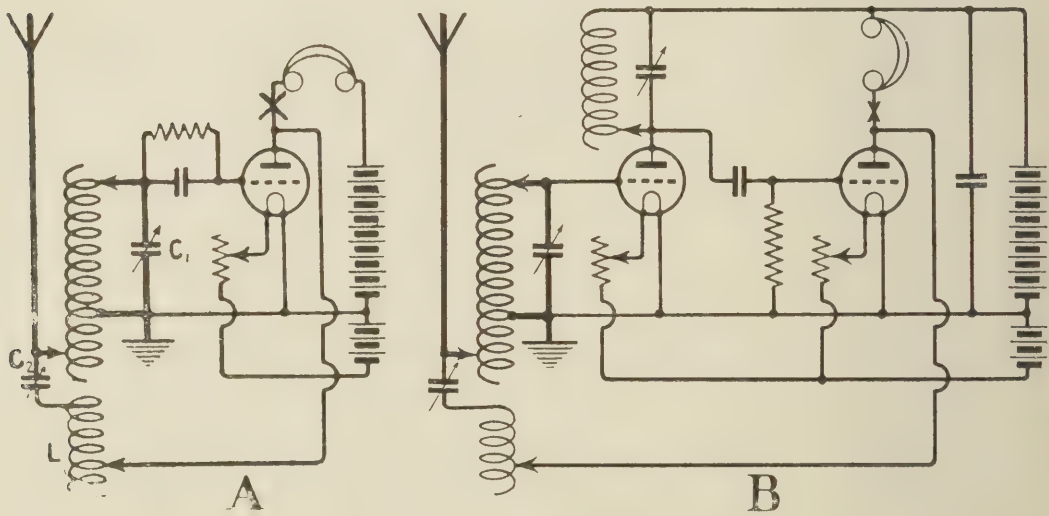


FIG. 171. **A** illustrates a single-valve arrangement of the Reinartz circuit, while **B** is a Reinartz circuit with H. F. amplification, published by the Author in 1922. In modern versions of the Reinartz circuit it is usual to insert a radio-frequency choke where indicated at X.

Any desired degree of reaction can be arranged by adjustment of condenser C_2 or reaction coil L. It will be noted that this circuit embodies a combination of electro-static and electro-magnetic reaction coupling.

High-frequency Amplification and the Reinartz Tuner (519).—The **Author** published a circuit in 1922 adding one stage of high-frequency amplification to the Reinartz tuner. This is shown in Fig. 171B.

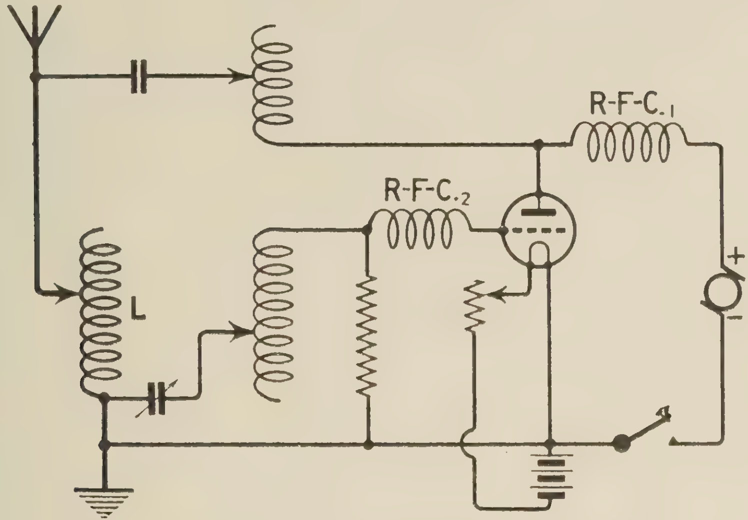


Fig. 171*C*. The Reinartz transmitting circuit.

The Reinartz Transmitter (520).—Fig. 171C shows an early transmitting circuit used by Reinartz and based on his receiving circuit. With this arrangement the wavelength transmitted is determined by the position of the aerial tap on

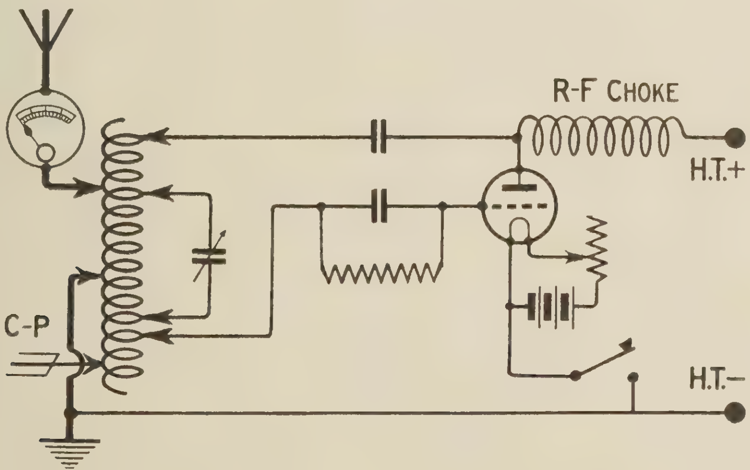


Fig. 172. A Hartley transmitting circuit with a counterpoise earth ; the purpose of the ordinary earth connection is referred to in the text.

inductance L. The small radio-frequency choke R.F.C_2 was used for choking out parasitic oscillations of a very high frequency.

THE HARTLEY CIRCUIT.—Owing to the fact that the oscillation circuit is under particularly good control, circuits of this type are very widely used by amateurs for short-wave transmission.

Fig. 172 illustrates one form of this circuit intended for use with a counterpoise. It will be noted that one coil with adjustable tappings, serves as A.T.I., grid coil, and reaction coupling.

To counteract any tendency to generate parasitic oscillations the nodal point of the coil is often earthed as shown.

INTERFERENCE PREVENTION.

Many methods of interference prevention and atmospheric elimination have been suggested.

MARCONI'S X STOPPER.—One of the earliest was **Marconi's** X Stopper. This is depicted in Fig. 173A, and is really a filter circuit.

FESSENDEN'S INTERFERENCE PREVENTER.—This is another of the earliest methods, devised by **Fessenden** and mentioned in Chapter XIV.

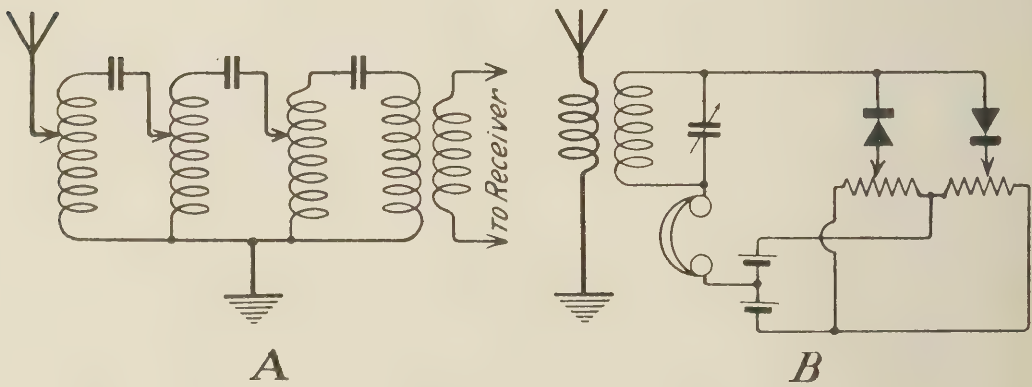


FIG. 173A. Interference may be reduced by employing a chain of filter circuits. **B** shows H. J. Round's Balanced crystal circuit.

PICKARD'S STATIC SHIELD (584), ALSO DIECKMANN'S CAGE (565).—**G. W. Pickard** designed a static shield or cage, to be placed round an aerial in order if possible to permit the reception of signals whilst rejecting static pulses ; neither this device nor a similar one employed by **Dieckmann** proved of much value.

L. LÉVY'S FILTER CIRCUIT.—In France an elaborate filter circuit has been devised by **Lévy**.

Loop Aerial Methods.—Refer to the works of De Forest, Brown, Pickard, Taylor and others in Chapter XVI.

H. R. de Bellescize's Differential Static Eliminator (1032).—In 1919 **Bellescize** patented a differential method in which one valve is employed for detection of both signals and unwanted atmospherics. Two further valve circuits are so balanced that the effect of the untuned statics is practically balanced out.

The Balanced Aerial Method (536), (108), (506), (684).—This is another method of interference prevention, in which two aerials are employed ; they are tuned to different wave-lengths and connected to a common earth. For receiving, two complete receiving circuits are employed, each fitted with a detector, and coupled respectively to the two aerials. By means of suitable transformers, having their secondary windings connected in opposition, and one pair of telephones, the operator listens in to both these circuits.

With this arrangement sharply tuned signals can be readily tuned in while any atmospherics which arrive affect both aerials simultaneously and tend to neutralize one another, so that even powerful atmospherics produce but slight effect in the phones. Several other balanced aerial methods are described in Ref. 536.

L. W. Austin's Method* (509).—**Austin** has shown an extremely simple method of static elimination, which has proved very satisfactory in practice. His method is to connect a silicon-arsenic contact between aerial and earth. This acts as a self-restoring coherer, while it remains unresponsive to signals of ordinary strength. When any powerful atmospherics pass down the aerial, the contacts cohere and the impulse passes to earth. A slight weakening of signal strength occurs at the moment ; but this is far less disturbing to the operator than the distracting crash of the atmospheric.

H. J. Round's Balanced Crystal Method (507), (508).—This method is illustrated in Fig. 173B, page 284. Two detectors are employed connected in opposition, one set so as

* **E. L. Chaffee** invented a method of interference limitation in 1917 (1054), in which he shunts the A.T.I. by a valve to act as a by-pass. In his patent, No. 157207 (now assigned to J. H. Hammond), he covers the similar use of crystal contacts, or very fine wires, having a positive temperature coefficient of resistance.

to be sensitive and the other arranged so as to be as insensitive as possible. Signals will then be almost normally received by the former ; but both detectors will respond almost equally to a powerful atmospheric and as the detectors are arranged in opposition, the received impulses will tend to cancel each other.

Interference Limiters (495), (496).—**G. M. Wright**, of the Marconi Company, has patented valve circuits in which valves of the three-electrode and four-electrode types can be employed to limit the effect of large changes of grid potential on the plate current, and thus limit interference from strong atmospherics, or interference from neighbouring stations.

Wright's Dimmed Valve Limiter.—Fig. 174A shows the arrangement of **Wright's** dimmed valve limiter.* This

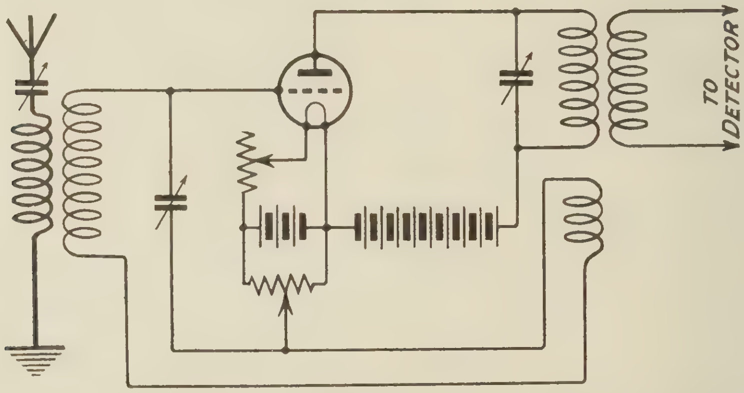


Fig. 174A. The circuit of Wright's dimmed-filament valve limiter

arrangement is coupled to the aerial circuit and to the receiver, and when the valve is dimmed (*i.e.* has its filament temperature lowered) it limits the strength of the signal and also atmospherics, all to one value, so that even an extremely loud atmospheric is only heard at the same strength as the signals.

Wright's Four-electrode Valve Limiter.—This is shown in Fig. 174B. The use of the coil L should be specially mentioned as it was a direct forerunner of the Hazeltine neutrodyne of which it is the magnetic equivalent. Coil L is coupled to coil L_1 in order to balance out the effect of the

* **W. T. Ditcham** (575) has shown that by dimming down a filament instead of working at rectifying point (when using a grid potentiometer) there is one point on the potentiometer where signals from one station vanish, and signals from another station will vanish at another point. Extremely fine adjustment is necessary—1/100-volt is enough to cut out one station or another.

capacity between the grid and the plate of the valve, and so annul the coupling between the grid and plate circuits taking place in the valve, the leads, etc.

See also in this connection the employment of the Dynatron and the Pliodynatron (488), (476).

L. B. Turner's Kallirotron Limiter (538), (536).—In this circuit, shown in Fig. 174C, two valves are connected with their filaments in parallel. Weak signals are amplified by this arrangement, while powerful atmospherics are actually reduced to a strength below that of the ordinary received signals.

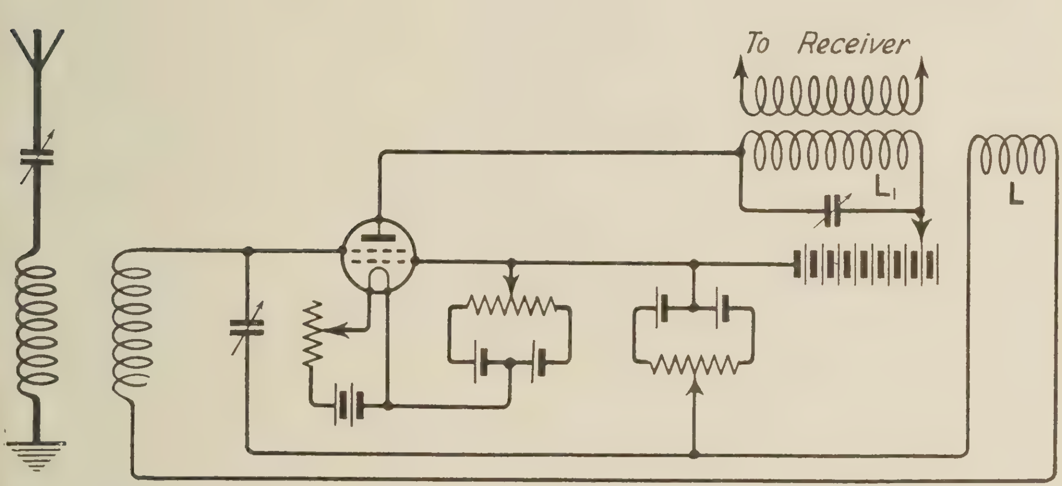


Fig. 174B. Wright's four-electrode valve, limiting device. The reversed coupling taken between L and L_1, is adjusted so as to annul the effects of any coupling between the grid and plate circuits.

E. L. Chaffee's Interference Limiter (1054).—Chaffee in 1917 invented a method for reducing interference which in effect is similar to Wright's dimmed valve limiter, in that it reduces the strength of loud signals while it does not materially reduce weak ones. The scheme consists of placing a thermionic valve across the grid condenser of a receiving valve in a receiving circuit in place of the usual grid leak. The method is illustrated in Fig. 174D. The grid of the valve is given a positive potential, and chokes L and L_1 are placed in the filament circuit to confine the potential variations to the plate filament circuit. In the patent specification (1054) it also says that a two-electrode or three-electrode valve may be connected across the A.T.I. or secondary tuning inductance to act as a "by-pass."

Hinton's Interference Preventor.—**N. P. Hinton** made considerable advance in this direction and invented apparatus which very greatly reduces interference. His apparatus was installed at the Leafield and Northolt stations, and at the G.P.O., London (503) in 1922.

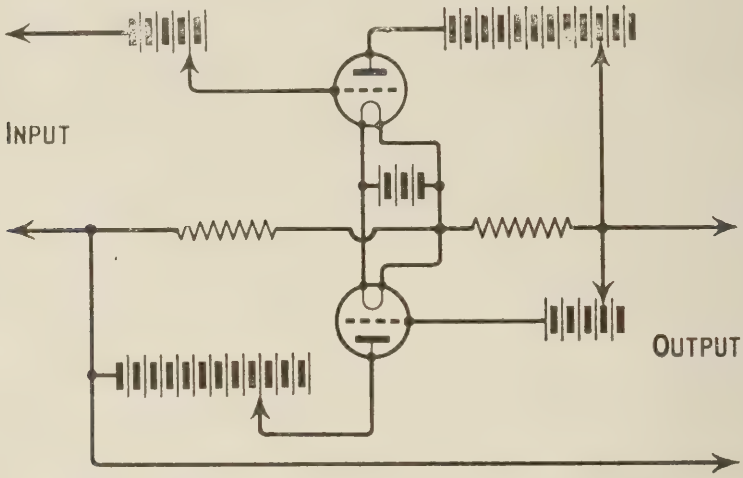


Fig. 174**C**. One of the applications of L. B. Turner's Kallirotron circuit is as a limiting device for atmospherics.

Some Simple Methods of Interference Prevention—Fig. 175A, B, and C shows a few simple wave-trap circuits which may be helpful to the experimental reader.* S in each

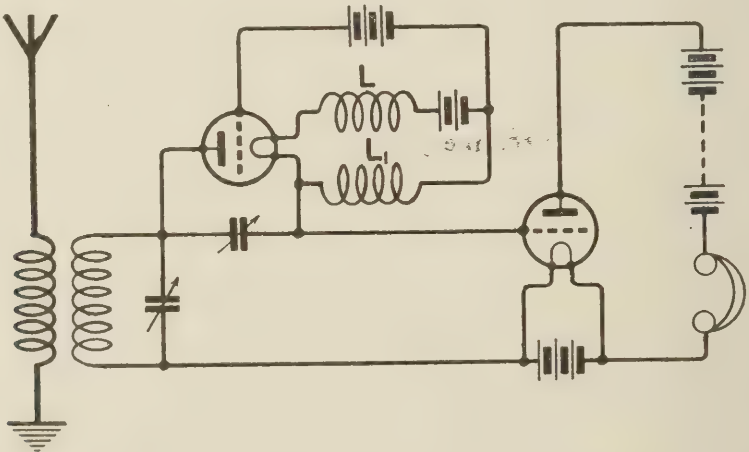


Fig. 174**D**. E. L. Chaffee's interference limiting circuit, employes a thermionic valve as a gridleak.

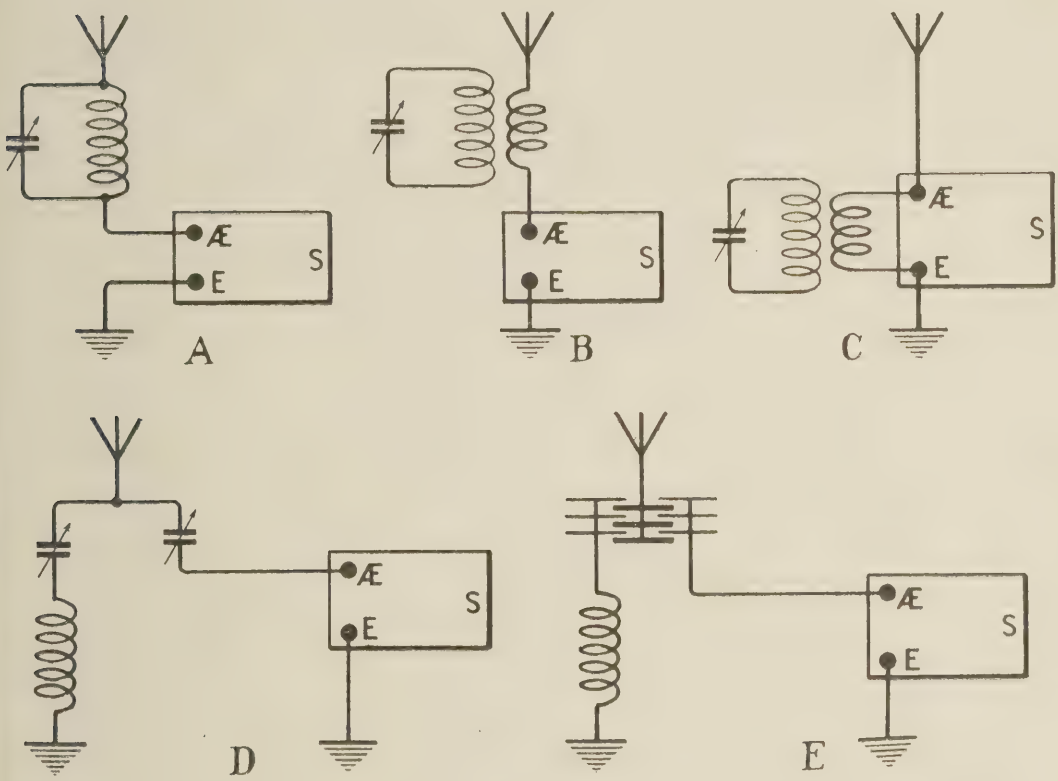
instance represents the existing wireless set which it is desired to protect from interference.

Fig. 175D represents another method in which two condensers are employed. This last method was improved on in

* See Ref. 504. Also **R. A. Weagant's** Method—Ref. (990), and the patents of **R. Whiddington** and **P. P. Eckersley** (968),)969).

1922 by the Autoveyors Company (505). For this purpose they employ a three-electrode variable condenser (see Fig. 176). This condenser is connected up in place of the two condensers as shown in Fig. 175E.

The aerial is connected to the centre vanes, the aerial terminal of the set to one of the other sets of vanes, and an inductance of suitable value is connected between the third set of vanes and the earth.



FIGS. 175**A** to **E** show a number of devices which may be employed to eliminate interference from an unwanted transmission.

RADIO-TELEPHONIC MODULATION.—In 1908, **Fessenden**, in a paper which he delivered at the American Institute of Electrical Engineers (358), made the following statement :

> " As a matter of fact the transmitter (*i.e.* microphone) can be placed almost anywhere in the circuit between the arc or dynamo and the antenna, or between the arc or dynamo and ground, or in the transformer circuit, or in shunt to an inductance or capacity ; the results in all cases being indistinguishable. The sole criterion of success seems to be that the transmitter should be capable of handling the energy, and the circuit should be properly

V

adjusted. Some success has been obtained by placing the transmitter in the field of the dynamo; but this method requires very careful design of the field circuit."

What Fessenden said in pre-valve days also holds, to some extent, for the control of valve generators, and with the introduction of the three-electrode and four-electrode valve many other methods have been added.

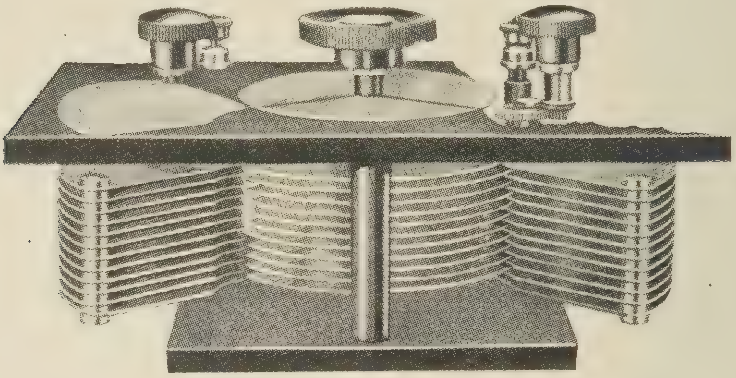


FIG. 176. The three-electrode variable condenser of the Autoveyors Company.

THE MODULATION OF VALVE TRANSMITTERS (718).—H. J. ROUND.—One of the first systems which employed a three-electrode valve as a source of oscillation for radio-telephony was that due to **H. J. Round** (456), (528). The connections which he employed are shown in Fig. 177A. from which it will be seen that he had placed his microphone M between the aerial and earth, as first suggested by **Fessenden** in pre-valve days. Using these connections, Round succeeded in his earliest experiments in telephoning over distances up to fifty miles.

The plate voltage was variable between 500 and 2,000 volts. R was a variable resistance made in four sections up to 10,000 ohms and capable of variation between this value and 500 ohms. The grid potential could be varied up to 500 volts.

Round has also employed both grid and anode control methods. In conjunction with the Marconi Co. he has filed several important wireless patents (see References 447, 486, 506, 507, 530, 540, and 602).

ROUND'S INTERMEDIATE CIRCUIT CONTROL METHODS.—Fig. 177B and Fig. 177C show two methods of modulation due to **H. J. Round** (447), (541), (108). Fig. 177B shows

the control placed in a coupling circuit between the plate and grid circuits, and Fig. 177C shows the microphonic control of the coupling between an oscillating valve and an amplifier.

I. LANGMUIR.—In 1915 **Dr. I. Langmuir** described two methods of wireless telephonic valve transmission in a paper before the Institute of Radio Engineers, and during the same

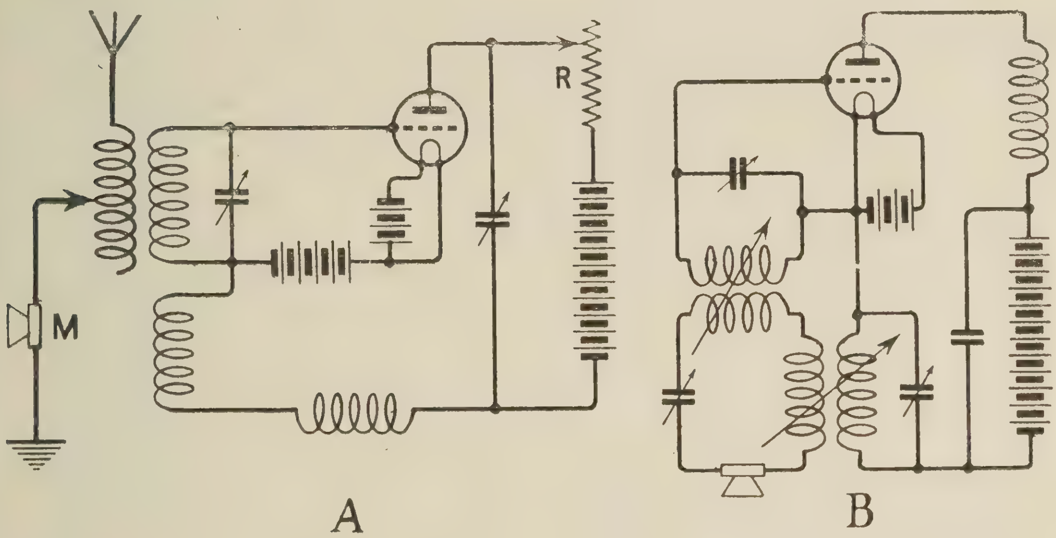


FIG. 177**A**. An early telephony transmitting circuit due to H. J. Round. **B** shows a schematic circuit illustrating Round's intermediate microphonic control method applied to an oscillator valve.

year the General Electric Company, of U.S.A., took out a patent (529) covering the amplification of the energy of original microphonic control before it was applied to vary the potential of the grid of the oscillator valve.

In 1916 the same Company patented a control system involving the use of a four-electrode valve having two grids.

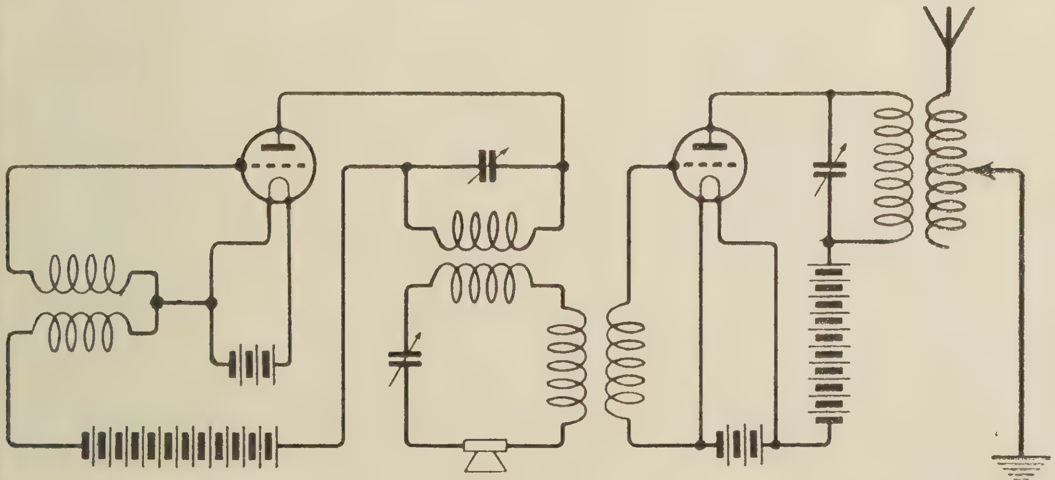
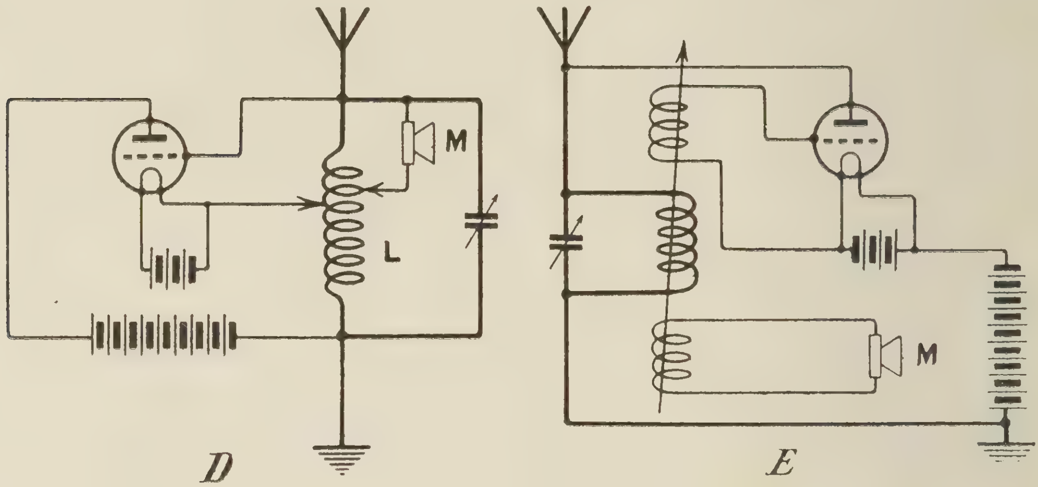


FIG. 177**C**. In this arrangement the microphone circuit is coupled to the oscillator output circuit and the input circuit of the amplifier.

Shunted Inductance Method.—Fig. 177D (79) shows a simple method of modulation suitable for a very small power single valve set. It is virtually the same method as that which Campos employed for controlling an arc circuit (see Chapter XI.).

The microphone M is connected across a few turns of the inductance L. The microphone in this case varies both the wave-length and the amount of the aerial current. Fig. 177E



Figs. 177**D** and **E** show two methods of modulation applicable to small power transmitters

shows another simple method of modulating small power transmitters (526). In this case the circuit containing the microphone M is inductively coupled to the aerial tuning inductance.

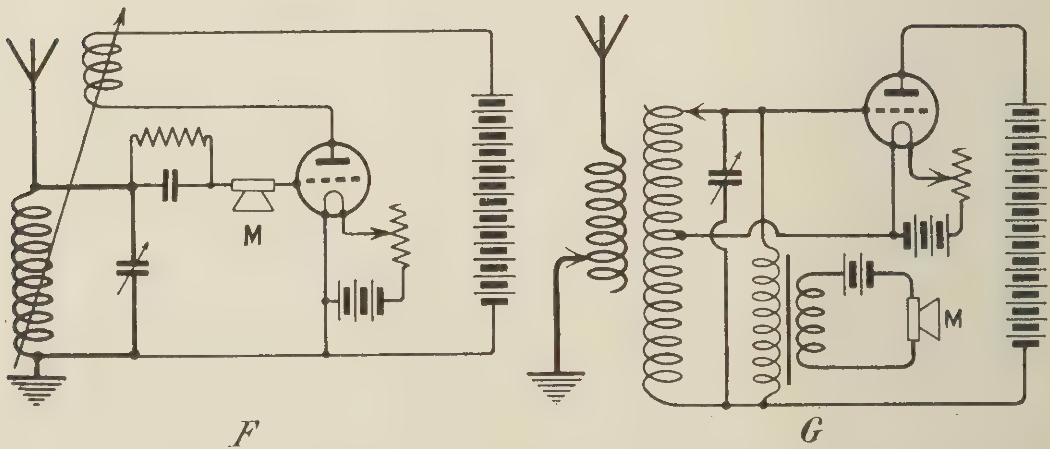


Fig. 177F. A grid control method possible with a set of small power. **G** shows another method in which the modulator is shunted across the closed circuit.

Grid Circuit Modulation.—Fig. 177F shows a very simple method of modulation which has been used satisfactorily by the Author for small powers up to 10 watts. The microphone M which must be of high-resistance type is placed in series with the grid. Fig. 177G shows another grid control method (456) in which the microphone is placed in the primary circuit of a microphone transformer in series with a battery.

Choke Control Method.—**Major Prince** described a very valuable method of modulation in a paper before the Wireless Section of the Institution of Electrical Engineers in 1920 (528). This method has proved most satisfactory and is a great deal used. It was originally designed for the Royal

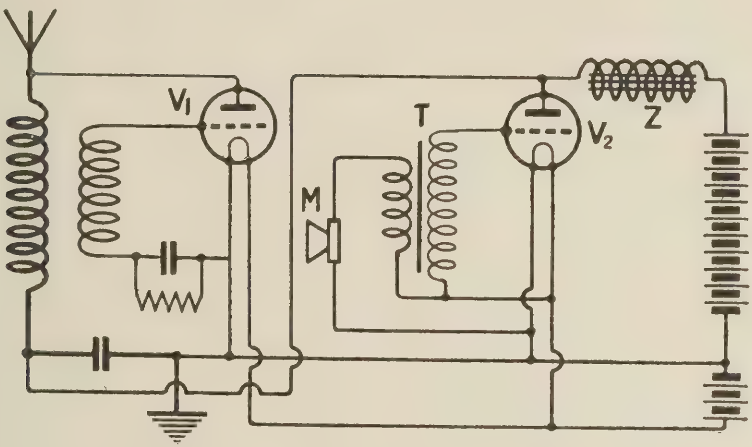


Fig. 177H illustrates the choke control method of modulation.

Air Force, for use on aeroplanes. The illustration shown in Fig. 177H is taken from Prince's paper before referred to.

V_1 and V_2 are two valves connected as shown. Z is an iron core choke. T is a microphone transformer. M is a microphone. Both valves are supplied from the same source of high-tension through the choke. The following, briefly, is the action of this arrangement, according to Major Prince : " As long as the microphone is quiescent the output and general behaviour do not differ from that of the power circuit considered as a plain one-valve oscillator. When, however, variations take place in the control valve anode circuit at speech frequency, very large surges are set up in that of the power valve which may approximate to the original high-tension D.C. potential and so sweep the output from nearly double its steady value to almost zero." . . . " Choke

control is of approximately double the effectiveness of one valve with grid control."

RESISTANCE CONTROL (542).—It is possible to replace the choke by a resistance of about 50,000 ohms, provided that the H.T. be increased sufficiently to overcome the voltage drop occasioned thereby.

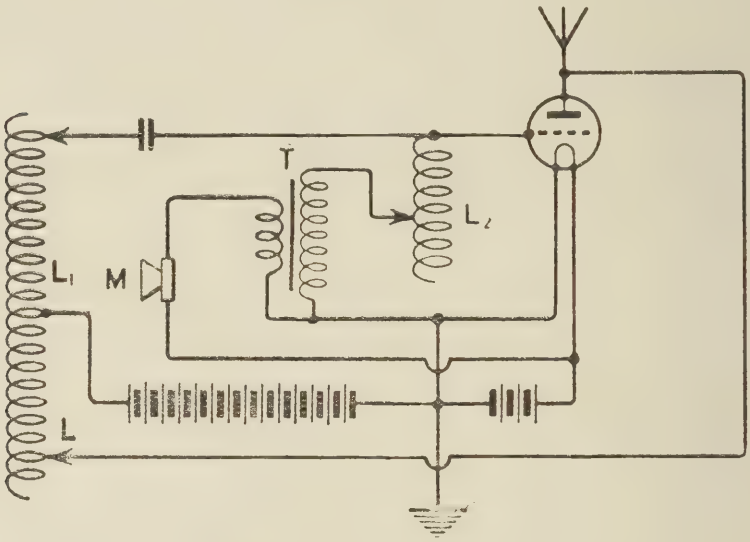


FIG. 177I. A modified grid control modulation circuit.

Fig. 177I shows another grid control method which, in practice, operates satisfactorily on wavelengths between 100 and 200 metres. T is a microphone transformer, M a micro-

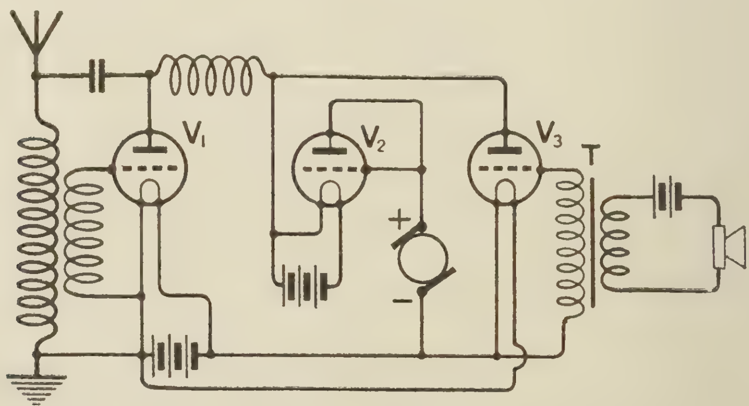


FIG. 178A. A schematic arrangement of Coursey's saturated valve control method of modulation.

phone, L_2 an inductance wound with fine wire, and L and L_1 are the plate and grid circuit inductances wound on one former.

COURSEY'S SATURATED VALVE CONTROL (542), (543).—In a paper before the Wireless Society of London, in 1921, **P. R. Coursey**, showed that a valve run at saturation point (*i.e.* at a point when a further increase of plate voltage gives no further anode current) could be employed in place of a choke provided that the voltage drop occasioned by the addition of this extra valve is made up for by increasing the supply voltage.

The exact degree of saturation as regulated by the filament current was shown by Coursey to be fairly critical.

Fig. 178A shows Coursey's diagram from which it will be seen that the grid and plate of the control valve V_2 are connected to one another in lieu of employing a two-electrode valve.

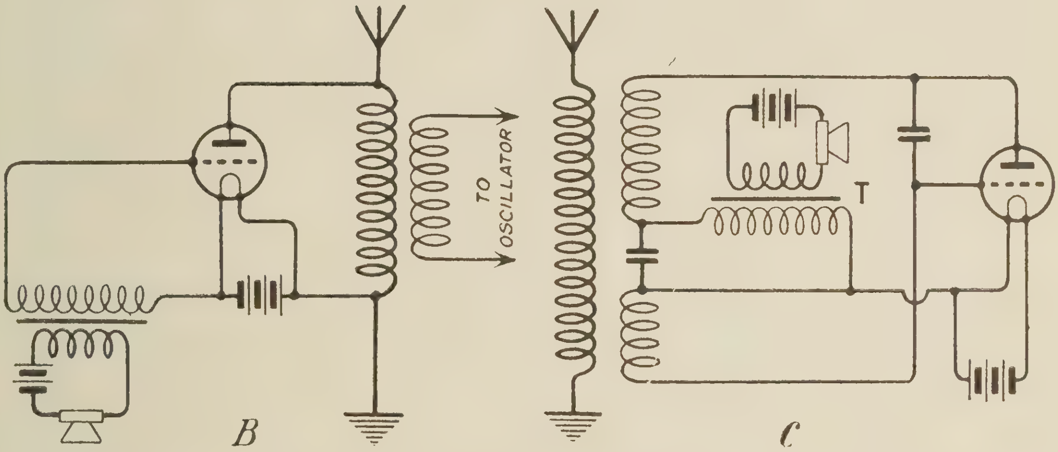


FIG. 178**B** shows a shunt control method of modulation. **C** is a simple circuit for quiescent aerial telephony transmission.

Coursey also showed that in place of using a separate three-electrode valve V_3 for microphone control the secondary of the microphone transformer T can be connected up to the grid of valve V_2 which would of course in that case be disconnected from the plate.

SHUNT CONTROL.—Fig. 178B shows a shunt control method also described in Coursey's paper above referred to. In this case the valve is connected across the A.T.I. which is inductively coupled to a valve or other generative circuit.

QUIESCENT AERIAL MODULATION (542), (549), (456), (783), (980—982), (992).—Fig. 178C shows one set of connections for small power quiescent aerial telephony. By quiescent aerial modulation we mean that the aerial is normally quiescent

(or non-radiating), and that it only radiates while speech is in progress.*

In this method the H.T. supply is obtained solely from the secondary of the microphone transformer T which is specially designed for that purpose ; but at best there is considerable distortion of speech (542). If an interrupter is placed in the primary circuit in place of a microphone it gives quite good results as a tonic-train transmitter and can also be employed for short distance duplex working.

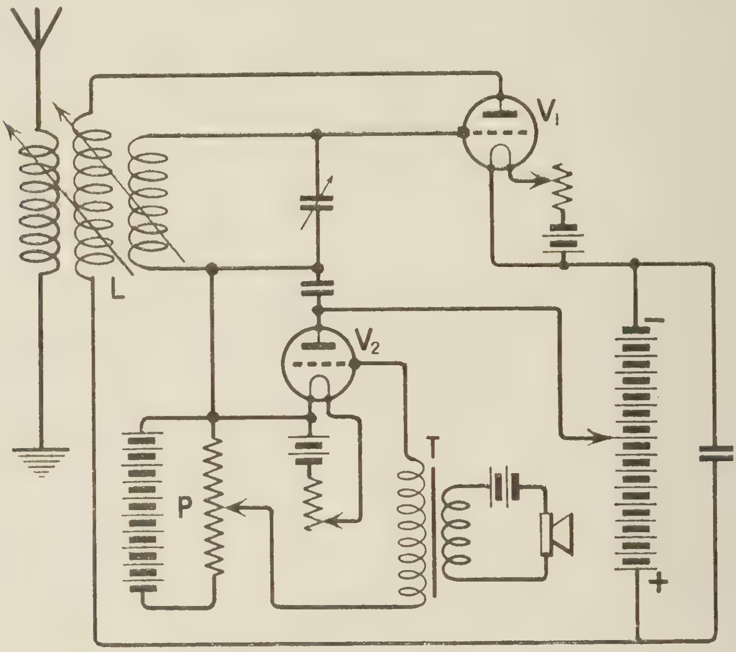


FIG. 178D. A quiescent aerial circuit in which the oscillation valve V_1, only oscillates during the actual transmission of telephony.

Fig. 178D is a diagram of a quiescent aerial circuit in which the generating valve only oscillates during speech (544).

With slight modification and small powers this arrangement has been employed for duplex telephony without any necessity for the usual switching over from transmission to reception.

Valve V_1 is the generating valve, its filament being connected to the negative supply and its plate through inductance L to the positive H.T. lead. V_2 is the modulating valve, which is connected to the same H.T. battery, or it may be connected to a separate H.T. battery connected to the filament of the generating valve.

* **Coursey** has shown the employment of saturated valve control for quiescent aerial working.

P is a battery and potentiometer by means of which the grid of the modulating valve V_2 is kept at a negative potential, connection being made through the secondary of microphone transformer T.

The grid and plate circuits of valve V_1 are both tuned to the same frequency. By suitable adjustment of the potentiometer P, valve V_1 can be made to oscillate or its oscillations quenched. A critical point will be found where the system is very unstable and any increase of grid potential on valve V_2 (such as those impressed on the grid by the secondary of microphone transformer T during speech) will cause oscillations of greater or less amplitude in valve V_1 according to the amount of such increase.

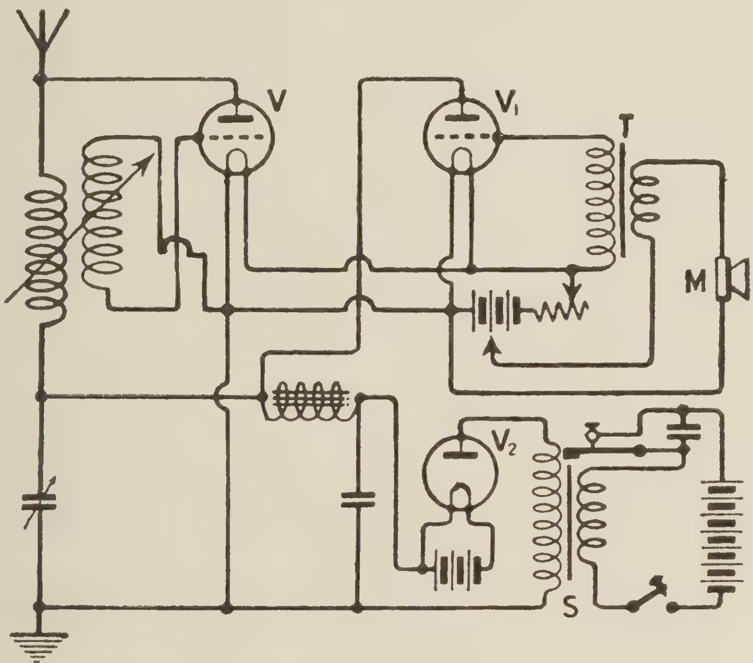


FIG. 179. A circuit for telephony transmission using a spark coil and rectifying valve as the source of H. T. supply.

ROUND'S METHOD OF TELEPHONY FROM SPARK COIL SUPPLY.—**Round** has also shown how thermionic valves can be employed for telegraphic and even telephonic transmission using a spark induction coil as the source of H.T. supply.

Fig. 179 shows such a circuit using a small one-inch spark coil and rectifying valve to obtain the H.T. supply. V. and V_1 are two ordinary three-electrode valves. V_2 is a two-electrode rectifying valve, T is a microphone transformer, and M a microphone. S represents the spark coil.

Communication Between the British Isles and Australia. (561.)

The following are a few of the worlds notable records in long distance radio-telegraphy and telephony achieved by the Marconi Co. employing Thermionic Valves.

The Marconi Company's Station at Carnarvon, Wales. —Fig. 180 is a photograph of the exterior of this station, reproduced by the courtesy of the Marconi Company. It was first equipped with a power valve panel holding 56 valves of the MT2 type. The power was supplied from a 300 K.W.

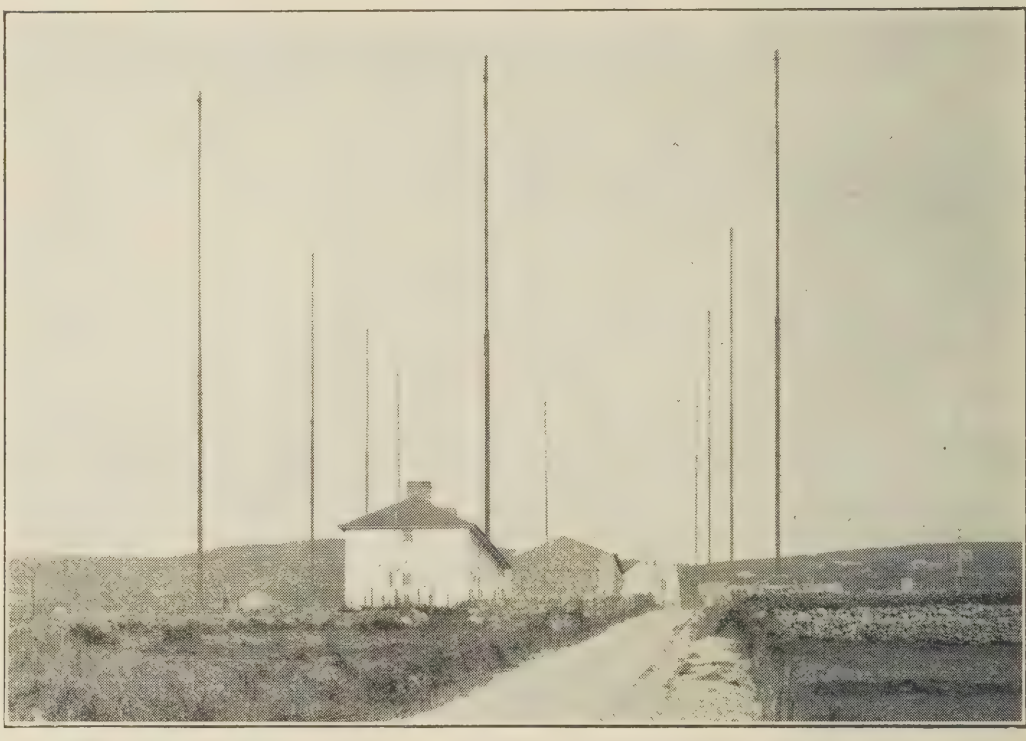


Fig. 180. The exterior of the Marconi Company's Station at Carnarvon, Wales

generator at 10,000 volts D.C. This station not only carries on a reliable daily transmission with America, but has been heard in Australia.

Fig. 180A (also reproduced by courtesy of the Marconi Company) is a photograph of the 56-valve panel at Carnarvon.

Carnarvon Signals Heard in Sydney.—November 19th, 1921,* will always be remembered as the occasion on which the Marconi Company, using valves for transmission, success-

* It is interesting to note that **Prof. Howe** gave his inaugural address to the Wireless Section of the Institution of Electrical Engineers, on November 9th of this year (1921). See Ref. (788).

fully bridged the entire world, when signals from their station at Carnarvon were read at Wahroonga, in Australia, by E. T. Fisk (561).

It will be remembered, from particulars given in Chapter XII., that signals from this station had already been read in Australia on September 22nd, 1918, on which occasion Marconi's "timed disc" was employed for transmission.

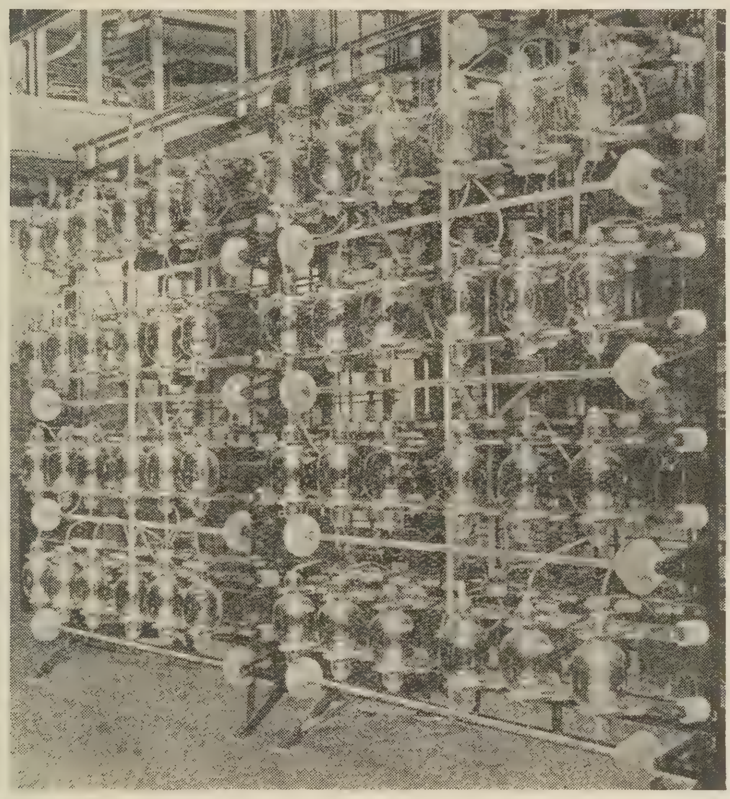


FIG. 180A shows large valve panel at the Carnarvon station.

SHORT-WAVE TELEPHONIC TRANSMISSION.—On May 30th, 1924, the Marconi Company established another world's record, when they successfully "telephoned" from their station at Poldhu, in Cornwall, to Sydney, in Australia.

The Poldhu station was equipped with oil-cooled valves. The power employed was 28 K.W.; and the wavelength 92 metres.* The messages were received quite clearly at the first trial by E. T. Fisk (819), (820).

* In connection with these short-wave transmissions it should be remembered that **Marconi** originally employed short waves during his earliest experiments. He afterwards abandoned them in favour of longer waves, until their practicability for long-distance signalling was demonstrated by the successful amateur transatlantic tests of 1922 and 1923. See Refs. (655) and (821).

CHAPTER XVI.

Direction Finding

(536), (537), (565), (663), (767), (127–156), (1040), (1046), (1057), (1064), (1074), (530), (1118), (1123).

S. G. BROWN. Also Elihu Thomson.—In 1899 (574).* **S. G. Brown** took out a British patent (567) for directional reception (575). A similar idea was also suggested at about this time in America by **Elihu Thomson.**

J. S. Stone.—In 1902 **J. S. Stone** took out a U.S.A. patent, covering an extended application of these principles (568). The general idea of Stone's scheme is depicted in Fig. 181A which is taken from an illustration in Stone's U.S.A. patent.

Two aerials, A and C, are spaced a definite fraction of a wavelength apart, and placed in the line of propagation of the waves as shown. They are connected to either end of the

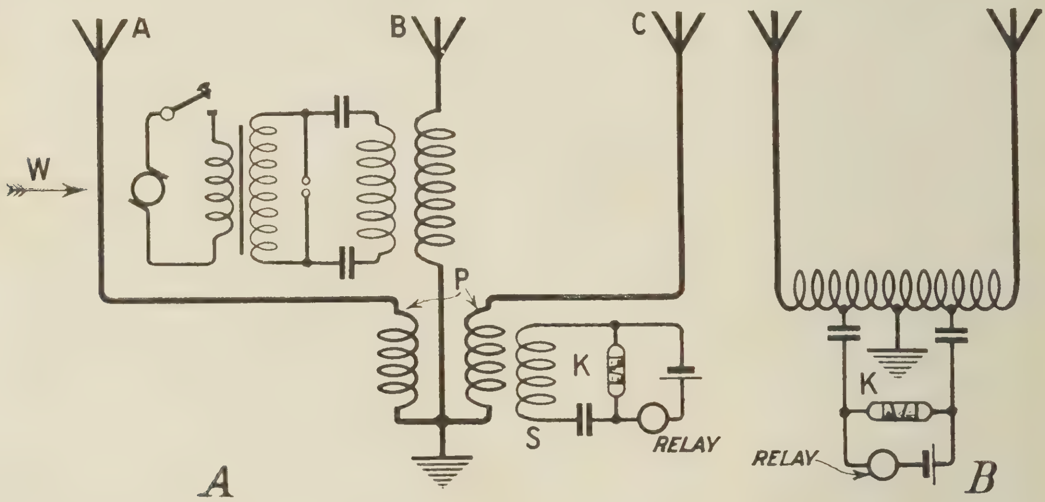


Fig. 181. **A** gives a general idea of Stone's scheme for directional Radio-telegraphy. **B** indicates another method patented by Stone.

opposed windings of a common primary P. Waves coming from the direction of the arrow W commence to affect the aerial A before they reach aerial C. The resultant currents produced in the two aerials arrive at the centre of the system in the primary P out of phase relation and set up currents in the secondary S connected to the coherer K. Moreover, if the

*It should be remembered in this connection that Hertz was the first to show how electric waves could be directed, this he did by means of parabolic reflectors. In the early days of wireless telegraphy, Marconi also employed parabolic reflectors.

distance between the aerials is equal to half the wavelength radiated the electro-motive forces set up in each of the aerials will be opposite in phase and will add together. On the other hand, if the direction of propagation is at right angles to W, so that the waves arrive at both A and C simultaneously, the oscillations produced in the two aerials will be in phase at the centre of the system, and by virtue of the opposed windings of P will neutralize one another, so that the receiving circuit is not affected. The centre aerial B is employed for transmitting as indicated.

Fig. 181B is another method patented by Stone embodying the same principle.

BRAUN (569). Also WEAGANT (565).—In 1906 **Braun** extended this method still further for the employment of several collecting circuits, as did also **Weagant** in 1919 working on similar lines.

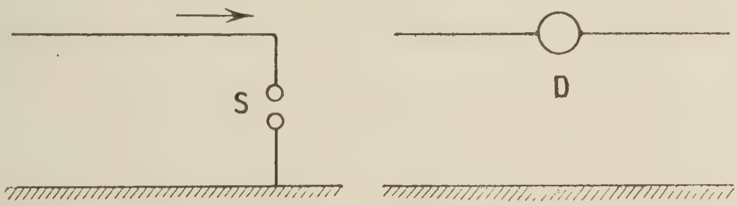


FIG. 181 **C** illustrates the directional properties of horizontal aerials.

ARTOM (152), (153), (156), (583), (864), (935).—In 1903 **Count A. Artom** devised a method of transmitting elliptically-polarized electric waves, by means of two aerials crossed at an angle of 90 degrees. By this means he projects a beam of waves in one direction (864).

MARCONI (571), (572), (865).—In 1905 **Marconi** showed that horizontal aerials have directional properties.*

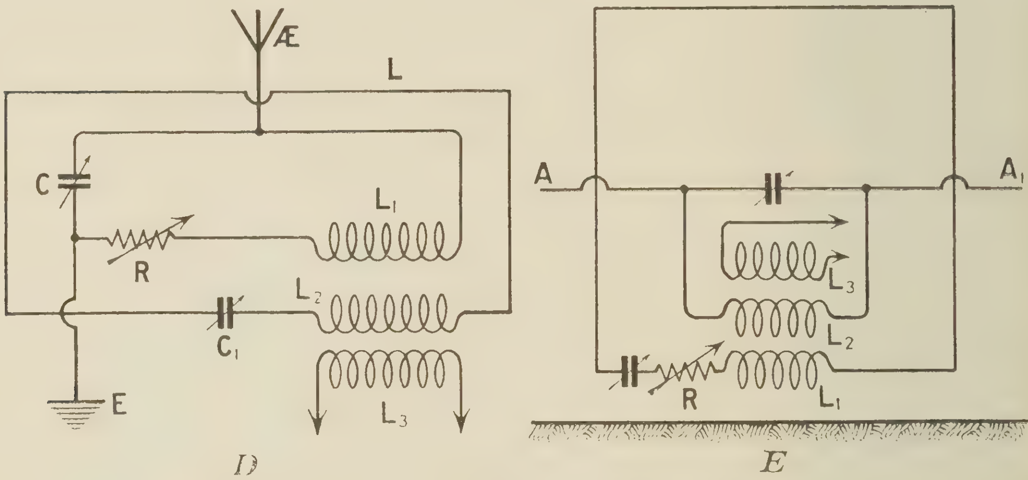
Fig. 181C illustrates this. For transmission he showed that an L-shaped aerial radiated most strongly in a direction indicated by the arrow in the figure. For reception he employed a horizontal aerial with the detecting instrument D at its centre. The aerial is so arranged as to be in a direct line with the transmitting station. His later patents include the employment of a wire or wires lying on the ground under the aerial and in the same direction (865).

DE FOREST FRAME AERIALS.—According to **Round** (575) the use of the frame aerial was probably first suggested by **Lee**

* A multiple wire " L "-shaped aerial was employed at the Marconi station at Poldhu (now closed and used for experimental work).

de Forest.* We can, however, trace back the principles governing loop reception to the early experiments of Hertz, when he demonstrated the directive properties of his single turn loop resonator (already described in chapter 4, page 54). In 1899 **Ferdinand Braun** used frame aerials for both transmission and reception.

G. W. Pickard (570), (685 to 691).—In 1905 **G. W. Pickard** devised a method which he patented in 1907. In this method a combination of loop and open aerial was employed. During 1907 and 1908, by the employment of a small three-turn loop aerial, about three feet in diameter, shunted by a variable condenser and a crystal detector, he mapped out the wave-front around a transmitting station (565). In his most comprehensive paper before the Institute of Radio Engineers (565), Pickard gives several open aerial and loop



Figs. 181 **D** and **E** indicate two circuits employed by Pickard.

combinations. Two of the best of these diagrams are reproduced in Figs. 181D and 181E.

In Fig. 181D, Æ, E is an aerial circuit, comprising an inductance L_1 in parallel with a variable condenser C, by which it is tuned, and having a variable resistance R in the circuit. The inductance L_1 is inductively coupled to inductance L_2 in a loop circuit L, C_1. Inductance L_2 is also coupled to a winding L_3, connected to a suitable detector. Resistance R is employed to enable the signals received in the open aerial to be balanced with those simultaneously received on the loop. Pickard carried out numerous directional tests with this arrangement at Otter Cliffs, near Bar Harbour, Maine,

* For data for constiuction of frame aerials see Ref. (662).

and was able to take down transatlantic messages through the heaviest static interference (576).

Fig. 181E shows another arrangement due to Pickard, in which an open horizontal aerial A, A_1, 50 metres long, was employed in combination with a loop aerial, raised about four metres above the earth, consisting of seven turns of wire wound on a former thirty metres across and seven metres high. As the loop was the more efficient receiver the resistance R was included in the loop circuit, and the detector was coupled to inductance L_2 by means of winding L_3. Pickard showed that wave fronts travelling overland were not vertical but tilted forward in the direction of propagation.*

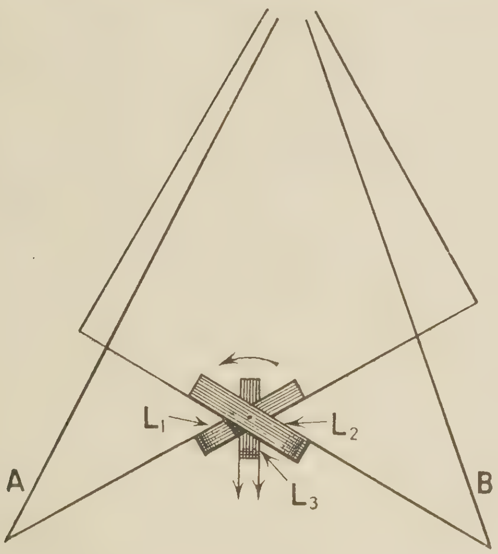


FIG. 181 **F** illustrates the original aerial system employed by Bellini and Tosi for their Radiogoniometer.

For example, the waves received at Otter Cliffs were inclined rather over fifteen degeees from vertical.

THE RADIOGONIOMETER OR THE BELLINI-TOSI DIRECTION-FINDING METHOD (575), (581), (582), (92), (594), (608), (866), (132), (147), (151), (1068), (1069).—An account of the work of **E. Bellini** and **A. Tosi** appeared in 1907 (565), (58). The original Bellini-Tosi aerial consisted of two wires, each bent into a triangular form, with the tops of the wires in close proximity, and arranged so that the planes of the two aerials were at right angles to one another. Both of them were fixed in a vertical position (4D), as shown in

* The Gesellschaft für Drahtlose Telegraphie, patented in November 1921, a method of correction for the directional errors due to inclination of wave-front, for use with frame aerials (585). **Admiral Jackson,** in his Presidential Address, before the Wireless Society of London, on January 25th, 1922, dealt very fully with this question (588). See also **L. W. Austin's** lecture before the Washington Academy of Science, in 1921 —Ref. (781),

Fig. 181F. These two nearly closed aerial circuits A and B, included respectively two inductance coils L_1 and L_2 at right angles, coupled inductively to a third coil L_3, capable of rotation inside coils L_1 and L_2. This coil formed the inductance of a closed oscillating transmitting circuit, or was employed in conjunction with a detector for purposes of reception.

If, when transmitting, coil L_3 is coupled tightly to coil L_1, maximum radiation takes place in the plane of the aerial A; but none at right angles thereto, and aerial B remains practically quiescent.

If coil L_3 is placed in a position between coils L_1 and L_2, so as to be equally coupled to both, then the radiation of the combined system is at a maximum in the direction of the plane of coil L_3.

The Marconi-Bellini-Tosi Compass is a very similar arrangement In this case two closed triangular aerial loops are employed at right angles to one another. Their height from the base to apex of each triangle is forty feet, and their bases are forty-two feet across.

The Telefunken Wireless Compass (92).—The Telefunken Company employ a radio-compass transmitting station in order to inform ships of their bearings, which obviates the necessity of the vessels being equipped with special direction-finding aerials. The compass station is fitted with a type of " umbrella " aerial, *i.e.* an aerial with a number of low horizontal aerials radiating outwards from the station, which is in the centre of the system. Each aerial in turn transmits a signal at regular intervals, always beginning at some fixed point on the compass, and working round in a clockwise direction.

The ship wishing to take its bearings " listens " for the loudest of the series of signals, *i.e.* those which are transmitted from the aerial pointing directly away from the ship.

The operator on the ship has a special stop watch, marked with points of the compass, by means of which he is assisted in following the course of the signals round the transmitting station. By taking readings from two such transmitting stations, the ship is able to ascertain its position correctly, and distance from shore.

The Marconi Compass (867).—The Marconi Company cover a very similar method for both transmission and reception in Marconi's 1906 patent.

Fessenden's Directional Aerials (868).—**R. A. Fessenden** was granted an English patent in 1907 for a special type of directional aerial consisting of a number of horizontal antennæ suspended from a low central mast, and radiating from it. A commutator is employed to connect the desired antennæ. Each one is grounded at both ends,* or resting on the ground. In the latter case radiating trenches are dug between the different antennæ, as Fessenden explains, " to cause a sudden change in the electrical conditions."

U.S. Navy Radio-Compass. For particulars see Ref. (802).

Radiophares or Radio-Lighthouses (92).—Many stations have been installed around the coast of France by La Société Française Radiotélégraphique. The stations transmit on a short wavelength, 150 metres, and have a range of about thirty-eight miles. Ships obtain their bearings by listening for the automatic transmission from these stations, which have complete advantage over visual lighthouses in foggy weather.

Lee de Forest's Aerophores (169).—In this connection it is interesting to note that **Lee de Forest** applied for a British patent in 1906, in which he describes transmitting stations for giving ships their bearings as " aerophores."

Robinson's Method of Direction Finding. (941).—**Robinson** described a method of frame aerial direction finding in the " Radio Review " of 1920 (573), (574),† which is as follows :

Fig. 182 represents two frame aerials, A and B, fixed rigidly at right angles to one another,‡ but being capable of rotation together. Coil L has exactly the same inductance as aerial B, but has quite small dimensions. D. is a two-way double-pole switch, by means of which either coil L or aerial B can be switched in as desired. E is a reversing switch, by means of which the leads to aerial B can be reversed at will.

The procedure, when taking bearings, is as follows : Firstly, coil L is switched into circuit and the aerials are rotated, and the system is tuned by condenser C till maximum strength is obtained. Switch D is then pushed over to the right, and coil L cut out and aerial B put into circuit in its place. Free use is now made of reversing switch E, and the position of the

* In 1920 **Hanson** and **Jones** patented a system consisting of an aerial having a variable condenser at each end buried below the surface of the ground (665).

† See also **C. E. Prince's** British patent 2457 of 1912.

‡ **Round** employed a frame aerial consisting of two equal and rigidly connected coils in 1913 (574).

W

aerials is altered until the intensity of the signals is equal for either position of the reversing switch. The direction of the incoming waves is then indicated by the plane of aerial A.

J. Erskine-Murray and J. Robinson (601), (212). For other of their directional work see Refs. (941), (943), (944), (946), (959), (960), (962).—In 1919 **J. Erskine-Murray** and **J. Robinson** patented a direction finding apparatus with one rotary frame aerial or goniometer coil.*

Round (602).—During the same year **Round** also patented an apparatus for compensating for the errors in direction-finding on board ship, with Bellini-Tosi aerials. The scheme provided the aerial fore and aft with chokes to reduce its receptive qualities.

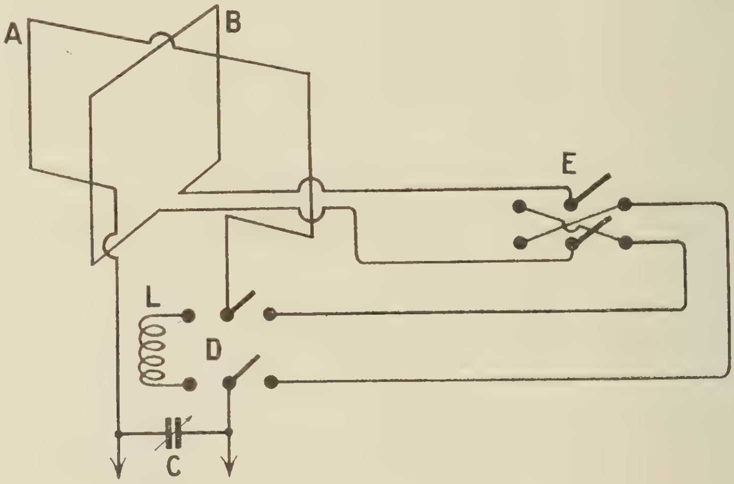


Fig. 182 illustrates Robinson's method of direction finding.

Trost (603).—In 1920 **S. O. E. T. Trost** patented an aerial system intended to determine the direction of the waves in three dimensions of space.

Van de Velde and J. M. Furnival (611).—Another ingenious device for aeroplanes was filed in 1920, and patented in 1921, by **Van de Velde** and **Furnival,** by means of which the search-coil of the radiogoniometer could be controlled by the rudder of the machine, so that as long as the signals were kept at minimum strength, a direct course could be maintained to the transmitting station.

C. E. Horton's Method of Predetermining Position for D.F. Apparatus when Building Ships.—In a lecture before the Wireless Section of the Institution of Electrical Engineers, in June, 1923, **C. E. Horton** summarized the

* See also **F. W. Dunmore's** loop aerial system (796) and (797).

problems of direction-finding peculiar to ships, and called particular attention to the errors in direction-finding caused by the proximity of large masses of metal to D.F. aerials. He also described the following laboratory method of determining beforehand, when building a ship, the exact distance at which any large metal object will distort the lines of magnetic force of the waves (633).

We will suppose it is desired to erect a frame aerial for direction-finding purposes, between two funnels (or other large metal objects) on a man-of-war. As it is a very costly matter to make alterations when once the ship is built, we wish to ascertain beforehand at what distance from a funnel, or number of funnels, the field will be sufficiently uniform to erect a Bellini-Tosi set.

The procedure is as follows : Take a large sheet of zinc, about 8ft. by 3ft. by 0·02ins. If this sheet is of perfectly equal thickness, it will be found, on passing a steady current of 20 amperes through it, that on testing by means of two needle points connected to a galvanometer there is a region near its centre where the flow of current is uniform (1122).

Holes are now cut to scale in this part of the zinc sheet, to represent the two funnels, and their distance apart. These two cavities in the zinc will affect the evenness of the current distribution in almost exactly the same manner as the funnels themselves will affect the magnetic field of the waves. A careful exploration by aid of the galvanometer and the exploring points of the region between the holes in the zinc will enable us to map out the area of distortion due to each hole, and to find a position where the flow of current is uniform. It has been found that this method is quite reliable and that when the ship is built and the funnels erected to scale there will be a corresponding area between them in which the frame aerials can be satisfactorily erected.

SWINTON'S EXPERIMENTS WITH A SHIELDED FRAME AERIAL (776).—In a paper before the British Association at Edinburgh in 1921 **A. A. Campbell Swinton** described a series of experiments undertaken with a frame aerial placed inside a large metal tube or wire spiral. The conclusion he arrived at was that the employment of the shield did not assist in improving directional reception.

A. H. TAYLOR'S DIRECTIONAL SYSTEM (668), (669), (670), (683).—A combination of a loop aerial and a horizontal wire shown in Fig. 183 is due to **A. H. Taylor**. This combina-

tion not only gives a fairly sharp directional effect, but also minimises atmospheric interference. L_1, L_2, and L_3 are inductances ; R and R_1 are resistances, while L represents the loop, and H the commencement of the horizontal wire.

Other Methods of Direction-finding.* Many other schemes have been devised, for which, amongst others, the following references may be cited : (612 to 633), (764), (802), (803), (932 to 964), (127 to 156), (169 and 170), (212 to 218), (1067), (1120).

A. Blondel's D.F. Receiver and Recorder (755).—In order to determine more accurately the maxima and minima of signal strength **Blondel** causes the received signals to

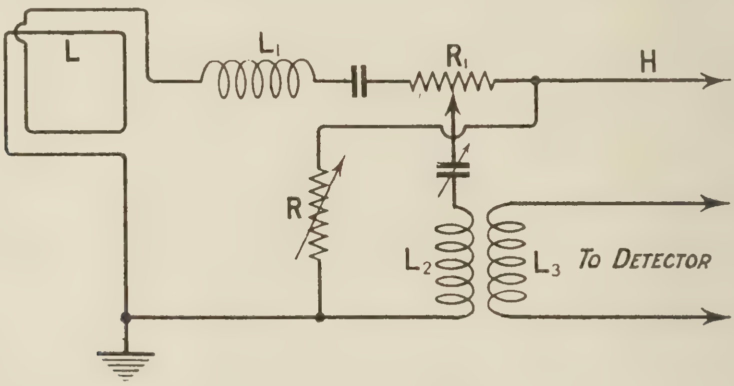


Fig. 183. The system due to A. H. Taylor utilises a combination of a loop and a horizontal wire.

operate an oscillograph and obtains photographic records on a chart controlled by the rotating frame aerial or radiogoniometer. The exact bearing is then found by geometry.

Screening Position of Station from Direction-finders (1057).—During 1923 and 1924 **Reginald Gouraud,** an American amateur, 8DZ, residing in France, carried out a series of transmissions in the heart of Paris, and for four months two goniometric stations at Issy-les-Moulineaux and Porte d'Orléans, situated on either side of that city working together were unable to locate his station.

Gouraud finally disclosed his position voluntarily. Actually, his transmitter consisted of two transmitters some distance apart. One of these carried on a telephonic transmission of a wavelength of about 1,500 metres, and this transmission was reinforced by the auxiliary station. The D.F. stations listening to this double transmission traced it to the Rond-

* Reference should be made to **J. Robinson's** paper to the Royal Society of Arts in 1924, in which the various methods employed during the Great War, and the various available methods, were described, followed by an extended discussion (1067).

Point in the Champs Elysées situated midway between the two transmitters.

MULTIPLE DIRECTION-FINDER (756), (757).—In a recent patent (756), **C. S. Franklin, B. J. Witt, G. M. Wright** and **S. B. Smith** have shown a method in which two frame aerials of the Bellini-Tosi type, at right angles to one another, are employed, in conjunction with two radiogoniometers. It is claimed that with this arrangement the system becomes doubly selective and doubly directional. It can be employed (*a*) to receive signals from two stations simultaneously, or (*b*) to receive two long-distance transmissions from different directions on the same aerials, even if the signals are of the same wavelength (757).

W. H. ECCLES METHOD OF PRODUCING COMPOUND RADIATION FIELDS BY MULTIPLE ANTENNAE SYSTEMS AND THE EMPLOYMENT OF A MASTER OSCILLATOR (1109).—In 1921 **Dr. Eccles** shewed that if two oscillating circuits, differing slightly in their natural frequencies, are coupled together, both circuits adopt a common forced frequency, but the oscillations in the two circuits differ in phase, and he shewed that the phase relation is variable (1) by alteration of the natural frequency of either of the circuits ; (2) by varying the magnitude of the currents or voltages of either of the valves.

He also disclosed that a three-electrode valve could be arranged to oscillate only when coupled to a second oscillating circuit.

He further shewed that if two oscillating aerial systems half a wavelength apart, having only slightly different natural frequencies, be coupled together (inductively through the air, or by other means) they mutually adopt a common forced frequency, but the waves of the two systems have a phase relationship which can be varied at will by altering the natural frequency of one of the systems, or by altering the position and form of the aerials.

By suitable adjustments such a system of coupled aerials can be made to radiate symmetrically or by altering their phase relationship a strongly directional radiation can be produced.

In his 1921 patent he also described how a triangle of coupled aerials can be made to vary its direction of strongest radiation by phase control, and he showed that separate aerial systems may be coupled to and forced into accord with a master oscillating system, which may be non-radiating.

FERDINAND BRAUN (4B).—In 1898 **Braun** conducted some experiments on the transmission of Hertzian waves through water in the disused moats of the old Strasburg fortifications.

F. KIEBITZ (92).—In 1911 **F. Kiebitz** carried out a series of experiments at Belzig with extremely low aerials, only one metre high, and about 240 metres long. He considered that they were superior to a vertical aerial forty metres high. He was able to receive signals on these " earth " antennæ from all European stations, and he transmitted, by their aid, to a distance of about 230 kilometres. (Refer also to **Hall's** ground wire aerial system (985).

THE BEVERAGE AERIAL* (590), (589), (591), (795), (159).—This is another aerial of a very low horizontal type. It is usually erected at a height of about twelve feet from the earth, and is used by the Radio Corporation of America for trans-atlantic traffic.

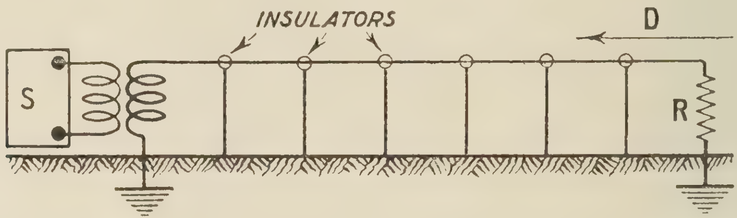


FIG. 184. The " Beverage " aerial is placed in line with direction of propagation of the waves to be received.

The potentials developed in this aerial are equal to those developed in a vertical aerial whose height is one-tenth of the length of the " Beverage " aerial (589). This aerial is shown in Fig. 184. It is directional, and is placed in line with the direction " D " of propagation of the waves. Its length is considerably greater than the wavelength of the received signals, and is determined by the following governing facts :

When the wave reaches the aerial it creates a current therein which will travel along the wire at a velocity determined by the electrical properties of the wire (resistance, inductance, capacity, etc.). This impulse will travel more slowly than the free wave, and the lag between the electrical forces in the wave and those in the wire will increase as the wave travels further and further along the wire, till at last a point will be reached when there is a maximum phase difference. After this a further increase in length will

* U.S.A. patent No. 1381089.

be of no further help in encouraging the growth of the E.M.F. in the aerial. It will begin to have exactly the opposite effect. We have now reached the correct length for maximum signal strength for the particular wavelength we are receiving, and any increase in length will only diminish the loudness of the signals.

When the wave reaches the set end of the aerial, the current is reflected back along the aerial and if allowed to do so would tend to reduce the E.M.F. therein. A resistance R is therefore inserted between the free end of the aerial and the earth, and arrangements are carefully made that the coupling unit at the set end S and the resistance at end R offer the same impedance to the wave as the aerial itself. The reflection effect will then be reduced to a minimum.

J. MURGAS (158).—In 1907 **J. Murgas** patented a method of signalling with buried antennæ. The aerials were well insulated and inserted vertically into holes in the ground.

J. HARRIS ROGERS (1024).—During the Great War, **Rogers** showed that it was possible to receive European communications in America by means of horizontal aerials buried below the surface of the ground, and he claims to have employed this type of aerial satisfactorily for transmissions.*

A. A. HALL (985).—In 1918 **A. A. Hall** patented a method of thermionic valve radio transmission and reception in which the usual elevated aerials are not employed. The transmitting and receiving stations each have two earth connections about an half-a-mile apart, connected to the sets by insulated conductors lying on the ground. For both transmission and reception valve circuits with reaction between grid and plate circuits are employed similar to those commonly used for reception and transmission. The negative side of the filament of the valve is connected to one earth, and instead of connecting the negative side of the H.T. supply to the same earth, it is connected to earth half-a-mile or so distant.

RECEPTION WITHOUT AERIALS (812).—**The Author** has pointed out that good broadcast reception can be obtained with any good single valve regenerative set with or without note magnification, at a distance of from fifteen to twenty miles from a main broadcasting station without the employment of any aerial in any of the following ways :

* Reference should be made to **P. R. Coursey,** page 228 of this book ; and Ref. (587) on signalling with submerged aerials from submarines.

(1) By connecting the grid of the detector valve to earth and leaving the usual earth terminal of the set free.

(2) By employing the same connections as above but with the addition of a variable condenser in the earth circuit. This arrangement is not very practicable, as it makes the set particularly sensitive to capacity effects due to the proximity of the operator's hands. This effect can be obviated to a great extent by connecting a high resistance across the condenser.

(3) A far better method is to connect two condensers in series across the aerial and earth terminals of the set, as shown in Fig. 158, page 270.

Ionized Beam Aerials and Conductors (979).—In 1916 **J. Hettinger** suggested the employment of searchlight beams, from tungsten arcs, mercury vapour lamps, or other sources of powerful ultra-violet radiation, the idea being to ionize the air, through which the beam (or plurality of beams) passed, and so render it electrically conductive. When such a beam is to be used as a transmitting aerial, electrical connection to the beam is made from the oscillatory circuits, by means of a wire net or metal grid through which the beam passes.*

A similar arrangement is suggested for reception. The ionized beam may be partly or wholly saturated by direct current, or low frequency alternating current, and the oscillations employed for signalling may be superimposed thereon.

Ionized Beams as Conductors (979).—Hettinger has also suggested the use of ionized beams as conductors for ordinary telegraphy or telephony.

The Author's Experiments.—During 1923 and 1924 the **Author** carried out some experiments with ionized air (810). The air was ionized by means of two small radium-coated spirals of copper wire. One of these was well insulated, and attached to the grid of a Marconi QX valve, and the other was connected to one pole of the secondary of a small induction coil, the other terminal of which was earthed. Signals were transmitted in this way by the passage of ions across the lecture room; but it was not found possible to transmit at a greater speed than twelve words a minute. The **Author** suggests that it might be advantageous to substitute radioactive grids for those employed by Hettinger.

* Not only would the ionized beam offer a high resistance, but having an indefinite length it could not be expected to oscillate at any definite frequency.

PERMANENT ELECTRIFICATION (1104) (1105).—**Eguchi Mototaro,** of the Higher Naval College, Tokyo, has discovered a method of electrifying a resinous wax mixture (similar to sealing wax) so that it retains its electrification for years (some samples prepared in 1919 still exhibited electrification in 1922). This permanent electrification may be compared with the parmanent magnetization of steel under the stress of a magnetic field.

The method of preparation is quite simple. The mixture is composed of Resin 50 per cent., Carnauba wax 50 per cent., to which is added a very small trace of Bees wax. The latter is apparently not essential.

The mixture, when hot, is poured into a flat pan and a metal-plate is placed on to the top of the mixture. The pan and plate, with the hot mixture as a dielectric, form the plates of a high voltage condenser.

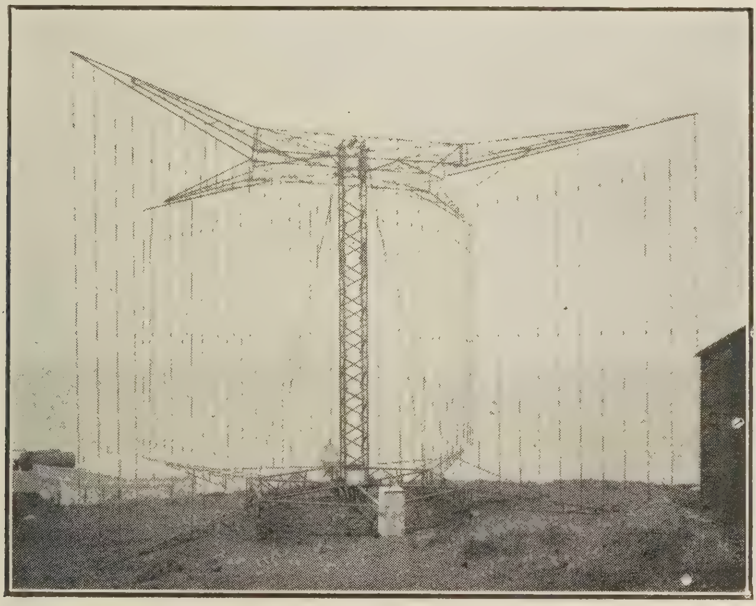


FIG. 185. Shows the Marconi Parabolic Revolving Beam projector at Inchkeith Island. (*Reproduced by courtesy of the Marconi Co.*)

The wax sets hard while subjected to an electrical stress, and when it is afterwards removed from the pan it is found to be electrified in the reverse sense to the applied electrification, *i.e.* the side of the wax on which the positive plate rested exhibits a negative charge while the opposite surface is found to be positive. These charges are, however, temporary and gradually die away in one or two days, after which, permanent charges of opposite signs grow to their ultimate value in a few days.

Scraping its surface, washing with acids, or exposure to a flame will destroy the charge temporarily, but it is quickly restored when the " Electret " is allowed to stand.

Many applications will doubtless be found, not only in Radio, but in all branches of Electrical Science, for this permanently electrified wax, called by its discoverer " Permenent Electret."

Short Wave Directional Wireless

(650), (649), (749), (819), (820), (1092), (1093), (1094), (1095), (1099).

Marconi and Franklin.—In 1916 **Senatore Marconi** and **Franklin** commenced a series of experiments in Italy with the object if possible of producing very short wavelengths, ranging from twenty metres to one metre. It was hoped to be able to construct reflectors, so that these short waves

Fig. 185A. In this photograph a Marconi Short wave receiving aerial is seen projecting from the bridge of the " Royal Scot." (Reproduced by courtesy of the Marconi Co.)

could be brought into focus and employed as " beams." Two-metre and three-metre waves were produced from a spark transmitter and by aid of reflectors the effective range was increased about three times. The reflectors were made

of a number of strips or wires, tuned to the wave, and arranged in parabolic form, having the aerial in the centre of focus. The transmitting reflector was capable of being revolved. A crystal detector was employed.

In 1917 these experiments were continued at Carnarvon. Signals were clearly received on a three-metre wave over a distance of twenty miles on a receiver without a reflector.

These experiments were made with the transmitter and the receiver at 600 feet and 300 feet above sea level respectively,

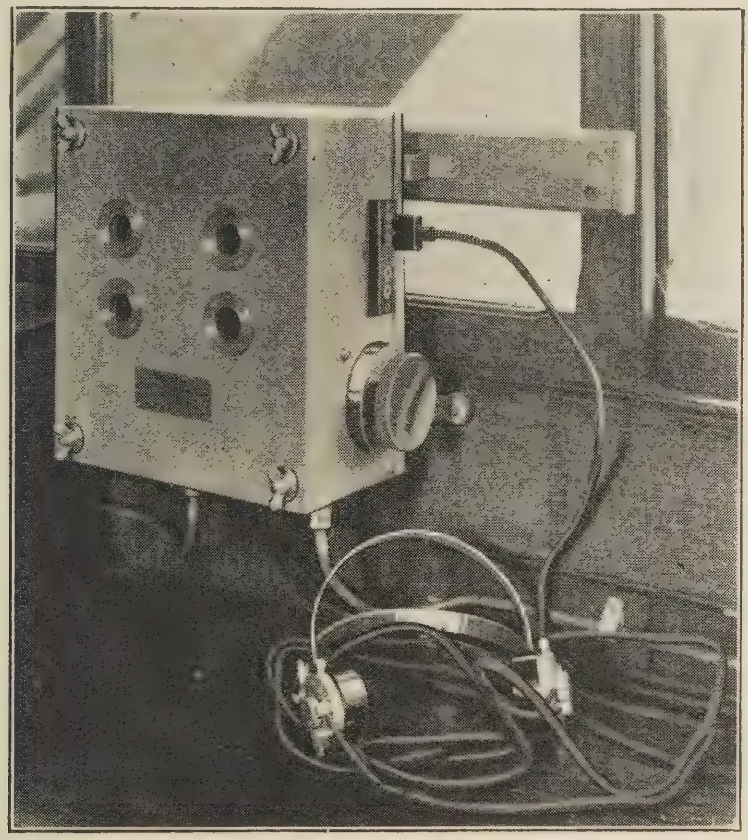


FIG. 185 B shows a receiver employed for reception of signals from Marconi's Revolving Beam Projector. (Reproduced by courtesy of the Marconi Co.)

there being a clear air line between them. A repetition of these experiments at sea level over sea with the same apparatus reduced the effective range to four miles.

In 1919 experiments were conducted at Carnarvon, with valve transmitters, with the object of attaining short-wave radio telephony, by **Franklin, White, Green,** and **Hall.** A 15 metre wave was chosen, and strong speech was heard at Holyhead, twenty miles distant, and eventually signals were received at Kingstown Harbour, seventy nautical miles distant. During the tests, it was found practicable to transmit and receive

simultaneously on the same aerial. The transmitting wave was employed to heterodyne the received signals. The transmitter was just left working and was operated when desired during reception.

In 1921 similar tests were made between Hendon and Birmingham, and duplex working was achieved. The wave-length employed at Hendon was only fifteen metres. The aerial was arranged in the centre of a reflector, pointing towards Birmingham. The signals were received at Frankley, near Birmingham, ninety-seven miles distant. Previously to the erection of the Birmingham station a motor-car, which was equipped with a suitable receiver, was able to receive very good speech to a distance of sixty-six miles, and fair speech in the Birmingham district. With reflectors in proper position at both stations the speech was very strong. When they were removed speech was just barely audible. Careful measurements proved that with reflectors the received energy was two hundred times as great as that received without their aid.

In 1920 a revolving reflector was erected at Inchkeith, and tests were made to SS. "Pharos," employing a four-metre wave, a spark transmitter, and a reflector having an eight-metre aperture. With a single valve receiver on the ship, a working range of seven nautical miles was attained. The reflector revolved slowly, making one revolution every two minutes, and a distinctive signal at each half-point of the compass.

Fig. 185 is a photograph of the reflector at Inchkeith, and Fig. 185A shows the type of aerial used for reception of beam signals. The aerial consists only of two short lengths of wire as shown. A receiver for beam signals is seen in Fig. 185B.

C. S. Franklin.—**C. S. Franklin,** at the end of his paper, before the Wireless Section of the Institution of Electrical Engineers, on May 3rd, 1922, from which the above is abstracted, gave a demonstration of short-wave directional telephony, the transmitter being placed in a revolving reflector.

This reflector or parabolic mirror consisted of an insulated framework, made so as to form a parabolic curve. A series of wires were stretched from the top to the bottom of the framework, parallel to one another. The aerial consisted of a short length of wire, placed in a vertical position, in the focal line of the reflector, and coupled inductively to the valve circuit.

G. MARCONI.—In his lecture before the Royal Society of Arts, in July 1924, **Senatore Marconi** referred to the fact that he had employed short waves and reflectors in his early experiments in 1899. He mentioned the suggestions of **Brown** in 1901 and **De Forest** in 1902* for the employment of reflectors, and also gave a most interesting summary of his further investigations in conjunction with **C. S. Franklin** and **G. A. Mathieu.** A long series of tests of "Beam Wireless" were carried out during April, May, and June, 1923, between Poldhu (Cornwall), where a reflector was employed, and his yacht "Elettra."† where a receiver was installed without a reflector.

The power employed at Poldhu was twelve kilowatts and signals were received right across Spain to a distance of 820 miles and later at Cape Verde Islands 2,230 miles distant, where strong signals were still received when the transmitting power was reduced to 1k.w. A wavelength of 97 metres was used during these tests.

SHORT-WAVE DUPLEX RADIO-TELEPHONY BETWEEN ENGLAND AND HOLLAND.—On December 18th, 1921‡ (652), a Marconi Company demonstration took place between London and Amsterdam, by means of a wireless link, connecting trunk lines in the two countries. The wireless stations at Southwold and Zandvoort were connected to the trunk telephone lines, made available for the tests by the postal authorities of England and Holland.

Short waves were employed, and duplex radio-telephony was carried on, with complete success, with a difference of only three metres between the wavelengths of the outgoing and incoming waves. Conversation was carried on in the ordinary way. One speaker could, at any moment, speak in answer to or even at the same time as the other, as in conversation.

SHORT-WAVE WORKING (USE OF VARIOMETER FOR).—The shorter the wavelength employed, the sharper becomes the tuning till at very short wavelengths it becomes a matter of considerable difficulty to get and keep the two stations in tune. A slight movement of the aerial in the wind, etc., when working at these exceedingly high frequencies, is

* **Lee de Forest** applied for a British patent in 19:6 (169) for the erection of "Aerophores" to give bearings to ships at sea. These "Aerophores" were virtually electromagnetic lighthouses, transmitting short wave "beams" reflected by a revolving parabolic reflector.

† For a description of the equipment of the "Elletra," see Ref. (829).

‡ For other duplex and multiplex methods, see Refs. (965–975).

sufficient to cause continual slight variations of frequency sufficient to put the communicating stations out of tune. A method of overcoming this trouble is to place a " variometer " of very small value in the aerial circuit. The variometer is rotated at high speed and its effect is to transmit a band of wavelengths following one another so rapidly that when the receiver is tuned to the centre of this band at any moment it is bound to pick up the signal on one or other of the adjacent frequencies.

A small variable and varying condenser could be employed in place of the variometer. This method if freely adopted would seriously reduce the number of stations able to use short waves, as each one would occupy too great a space in the limited number of wavelengths available. It would also be a wasteful method, in which much energy would be lost.

" Calling-up " Devices (644), (645), (168).—Many schemes have been devised to enable one station to call up another, to obviate the necessity of the operator being on constant duty, " listening in." Amongst others, the following may be mentioned :

Marconi Company Call Device.—In 1920 the Marconi Company gave a demonstration with one such device at their Chelmsford Works (644). A series of dots was transmitted at a frequency of 180 per minute, controlled by a small oscillating flywheel. At the receiving station these signals operated a three-valve amplifier, which passed the received impulses through electro-magnets controlling a balance wheel, having a natural oscillation period of 180 per minute. When the amplitude of the oscillations of the latter had built up to a sufficient extent, a contact was closed, and a call bell operated.

Binyon.—Major Binyon demonstrated a most ingenious call device to the Wireless Society of London on April 30th, 1920 (645), also (168). In this lecture he attributed the device to the inventive genius of **L. B. Turner** and **W. H. Shephard,** " whose several inventions have been combined by **Captain Lee** into the complete device."

Turner-Shephard-Lee Call Device.—This mechanical call or watch-keeping apparatus can be attached to any radio-receiver, in place of the 'phones. It consists of a Turner valve relay (as described in Chapter XV.), in conjunction with a Mechanical Selector. A full description of this device was given. It consisted of a number of contacts or brush

arms, radiating outwards from a hub. Each Morse dot or dash makes the hub revolve one notch in clockwise motion. The brush arms are of springy metal, and press against either the upper or under side of a contact ring. There is a gap in its circumference, so that each brush arm in turn passes across this gap, and can be deflected upwards or downwards, so that it travels round the upper side or the lower side of the contact ring, as the case may be. The mechanism is so arranged that a dash always causes an arm to be deflected upwards and a dot causes a downward deflection. The contact ring is itself an insulator, but at suitable positions, above and below, it is supplied with contact studs, which engage with the brushes, and complete a local call bell circuit only when the arms are in certain prearranged combination.

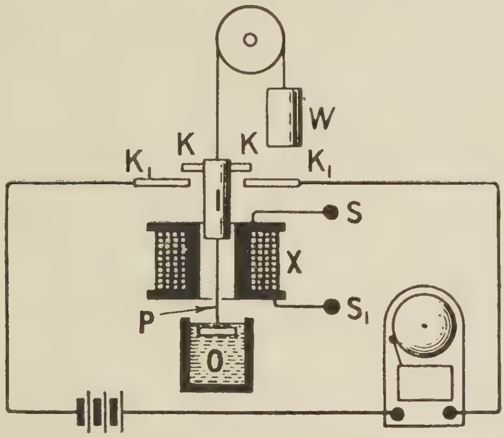


FIG. 186 illustrates a call device shown by Fleming.

The local call bell circuit is completed when the letters S O S are twice repeated. This double repetition of the distress signal obviates the accidental occurrence of false calls during an ordinary Morse message, when S O S happens to be present in it, as in sending the words " so slowly." In addition to the distress call combination, other combinations of contacts are arranged to ring the bell in response to the Morse call letters of the ship. No other signals are able to produce a combination which will switch on the call bell.

The device therefore acts as a kind of brain and analyses all the received signals, and responds when either of the above combinations occur. When the operator hears the bell, an indication in one or other of the circuits tells him if he has received a distress call or a call to his ship.

FLEMING'S CALL DEVICE (489), (646).—**Fleming** showed a very simple call device, in a paper before the Wireless Society of London, in December, 1920.

It is illustrated in Fig. 186. X is a solenoid of wire, connected by terminals S and S_1 to a relay actuated by signals. I is an iron core, suspended over a pulley wheel, and balanced by a weight W. At the lower end of the core is a plunger P, submerged in a vessel O, containing thick oil. If the key of the transmitting station is held down for a couple of seconds, the solenoid draws down the iron core very slowly, owing to the viscosity of the oil, and a local bell circuit is completed by contacts K, K_1.

This device will only respond to a prolonged signal. The time lag due to the viscosity of the oil makes it quite insensitive to ordinary Morse signals.

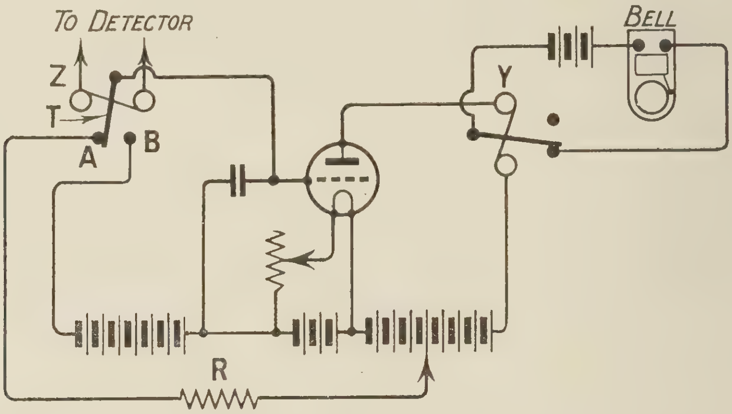


Fig. 187 shows the general arrangement of a call device by the Radio Communication Co.

The Radio Communication Company employ an automatic call device, which rings a bell, after a dash of prearranged length (479). The result achieved with this apparatus is similar to the Fleming arrangement just described. But, in this case, instead of using the plunger in oil, the necessary time lag is obtained by the slow discharge of a large condenser through a high resistance. (For example, it takes nearly half a minute to discharge a 6μF. condenser through one megohm.)

The charged condenser is arranged across the filament and grid of a triode valve, and keeps the grid strongly negative. When a prolonged signal arrives, the condenser discharges through a resistance, and a current passes through a relay in the plate circuit, and rings a call bell. Morse signals only begin to discharge the condenser, which recharges in the time intervals between the dots and dashes. It requires a very prolonged dash to discharge the condenser, and so remove the negative charge from the grid, and allow the plate current to operate the relay.

Fig. 187 shows the general arrangement of the circuit. By connecting the resistance R to the plate circuit battery, the grid can be made positive, when the condenser is discharged, so that a considerable plate current can pass through the valve to operate the relay Y. Relay Z is operated from the detector circuits not shown. While its tongue T is in contact with stud B the condenser is charged, and when it comes into contact with stud A it commences slowly to discharge.

Another Simple Call Device.—D, in Fig. 188, is the diaphragm of a telephone T connected to a wireless receiving circuit. To the centre of this diaphragm is attached a fine thread S, S_1, which passes once round the circumference of a small wheel or drum P, and is kept taut by means of a spring Q. A short lever or arm projects from the wheel P

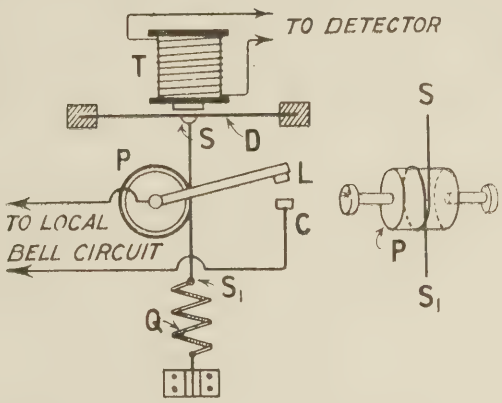


Fig. 188 illustrates the "Slipping Thread" call device.

and acts as one contact of the local bell circuit. This lever is only prevented from falling down and making contact with a stud C by the tension of the thread S, S_1.

When the diaphragm of the telephone vibrates in response to signals the lever slowly falls until the local circuit is closed.

Neon Tube Call Device (751).—**Coursey** has suggested the employment of Neon tubes for call devices arranged to respond only to signals of premeditated length. (See particulars under heading of "Application of Neon tubes to Radio Science.")

The Application of Neon Tubes to Radio Science (672–678), (750), (885), (226).—In 1904 (672), **J. A. Fleming** showed that a partially-exhausted tube, containing a certain quantity of Neon gas, was peculiarly sensitive to the influence of an oscillating field, and when brought near to an oscillating circuit, the Neon became luminous.

By the aid of such tubes, he was able to study experimentally stationary waves on spiral wires (674), (677).

At a meeting of the Physical Society, in 1922, **S. O. Pearson** (676) demonstrated the production of electrical impulses by means of Neon tubes, of the type manufactured by the G.E.C., under the name of Osglim (752)*. No current will pass through these lamps until the potential difference between the two electrodes reaches a critical value. When once the discharge through the tube is thus started, the voltage may be considerably reduced. Pearson gave in his paper a series of curves to illustrate this (750), (676).

FIG. 189. Is a reproduction of an Osglim lamp.
(By courtesy of the General Electric Co.)

When it is desired to use an Osglim lamp as a neon tube for wireless experimental purposes the special balancing resistance should first be removed from inside the cap, at the base of the bulb, so that contact can be made directly with the two electrodes (750).

Fig. 189 is a photograph of an Osglim neon-filled lamp.

Fig. 190 shows how a neon lamp may be employed for the production of electrical impulses.

C is a variable condenser; R a variable resistance; N is a neon tube; B a high-tension battery or high-tension voltage supply; L.S. is a loud-speaker.

As soon as the H.T. is switched on an interval will elapse while a charge builds up on the condenser. The time of this

* These lamps are sold for nightlights, signs, illuminated indicators, etc., and have a current consumption of 5 watts.

interval will be dependent upon the size of the condenser and the resistance in circuit. If the condenser be small, the voltage across its plates (*i.e.* across the neon tube) will rapidly reach the critical value of the tube. When this occurs, the lamp glows, and the energy required to maintain the glow will be derived (1) from the condenser; and (2) from the H.T. supply, depending upon the resistance in circuit.

The condenser, in discharging, will reduce the voltage across the neon tube to a value below that required to maintain the glow.

The glow will cease and the lamp will again present an enormous resistance to the charging current, which will recommence to charge the condenser, and this cycle of events will be continuously repeated. An increase in the capacity of the condenser, or an increase in the value of the series resistance, will have the effect of reducing the number of impulses through the lamp and loud-speaker.

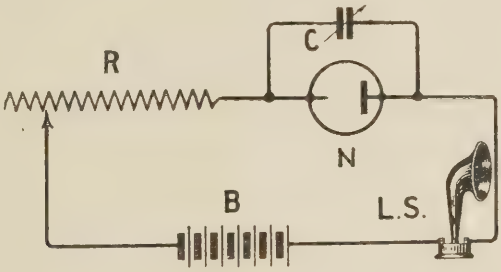


FIG. 190 illustrates the employment of a Neon lamp for the production of rhythmical electrical impulses.

Intervals as long as one minute between each impulse can quite easily be obtained.

OTHER APPLICATIONS.—**Coursey** has shown (751) that an Osglim lamp, if connected across the condenser terminals of a simple wave-meter, makes a very convenient indicator, for testing the wavelengths of C.W. or spark transmitting circuits. As these neon lamps are capable of passing current much more readily in one direction than in the other they can be used for rectification, which, though imperfect, would certainly suffice for the charging of small accumulators from A.C. mains.

Coursey has also suggested the probable use of these lamps with condensers, etc., " for making selective arrangements for relays at a receiving station, so that they will respond only to signals of a predetermined number of seconds in length, and not to shorter or longer ones."

These neon lamps can be employed as oscilloscopes for the examination of the wave-form of speech currents and other purposes (751). Neon tubes have also been employed for the detection of electro-magnetic waves. (See Claude's Neon Detector, Chapter VII. page 93).

THE ANSON NEON TUBE RELAY* (750).—Fig. 191 shows a method invented by **H. St. George Anson,** in which a neon tube is used in the plate circuit of a valve to operate an ordinary post office high-resistance relay. The neon tube, so employed, greatly reduces the time constant of the circuit, and the whole relay action becomes much more reliable.

In addition to suppressing the spacing current† (*i.e.* the current in the plate circuit of the valve when no signals are being received), a very effective change of plate current is obtained for each received signal, without loss of sensitivity.

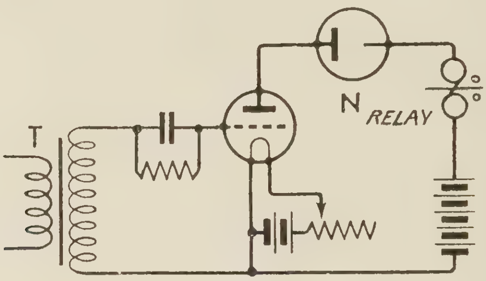


FIG. 191 is a diagram illustrating the general arrangement of Anson's Neon Tube Relay.

T, Fig. 191, is an ordinary low-frequency intervalve transformer, with a step-up ratio of about 5—1. The plate voltage employed is about 240 volts. The grid condenser has a capacity of 0·01μF., and the grid leak is of about two megohms resistance.

With this arrangement signals at a speed of 200 words per minute have been successfully recorded.‡

THE DOWLING "ZERO SHUNT" CIRCUIT (1112–1116).—In 1921 **John J. Dowling** of Dublin University showed a method by means of which it was possible to place a delicate galvanometer in the plate circuit of a valve, so that exceedingly minute changes of capacity in the grid circuit could be recorded by galvanometer movements.

* Manufactured by Messrs H. Tinsley & Co., British patent No. 214754.

† Up to this date, either a high resistance or a crystal was usually inserted in the plate circuit, in series with the relay for this purpose ; or the grid of the last valve of the amplifier was made sufficiently negative to make the valve work at the bottom of its characteristic curve, the relay being inserted in its plate circuit.

‡ Refer also to the Author's zero shunt method, Fig. 192.

His method consisted of placing the galvanometer in series with a high-tension battery in the plate circuit, and then balancing out the steady plate current which would ordinarily pass through the galvanometer by the application of an opposing E.M.F. supplied by a small battery through an adjustable resistance in a circuit shunting the galvanometer. By this means the galvanometer reading could be brought to zero even when several milliamperes were passing through the plate circuit of the valve. The sensitive galvanometer then functioned as an " Ultra-micrometer,"* and registered exceedingly minute current variations due to changes in the electrical constants of the grid circuit. This circuit has been employed for many laboratory purposes such as : Measurements of frequency and amplitude of H.F. oscillations ; the determination of the correct coupling between circuits ; the measurement of exceedingly small changes of capacity ; for the measurement and recording of minute changes of length such as those which take place during the growth of plants ; for Seismometric recording, etc.

G. G. BLAKE'S ADAPTATION OF THE "ZERO SHUNT" CIRCUIT FOR RECORDING SIGNALS.—This arrangement is so sensitive that it is possible to record even comparatively weak signals direct from a single valve circuit.

The **Author** employes an ordinary straight circuit as shown in Fig. 192. L_1 is the A.T.I. tuned by a variable condenser C_1. L_2 is a reaction coil in the plate circuit which also includes the H.T. battery, the primary circuit of a sensitive relay R, a galvanometer G, and a pair of headphones T. C_2 is a variable grid condenser and R_1 a fixed grid leak. R_2 is a high resistance included in the zero shunt circuit.

The secondary circuit of the relay includes a battery and a recording instrument. Reference to the work of Dowling (see references above) will show one or two new features in this arrangement. The E.M.F. for the " zero shunt " circuit is obtained from the filament battery by means of a potentiometer P instead of from a separate battery. In addition to the control obtainable by means of the potentiometer, or by variation of the resistance R_2, the galvanometer reading can be controlled and the pointer brought to rest at zero or on either side thereof, by adjusting the grid condenser C_2. The method of operation is as follows :—The received signals are

* Refer also to *R. Whiddington's* heterodyne method of measuring minute capacity changes, etc. ref. (1117).

first picked up in the headphones T by tuning in the station in the usual manner by means of condenser C_1. The current passing through the galvanometer G and the relay R, is brought approximately to zero by adjustment of the potentiometer P, and, finally, fine adjustment is obtained by aid of the variable grid condenser C_2, until in the absence of signals, perfect zero setting is obtained. The relay is then carefully set until it responds to the signals, as heard in the phones or observed by galvanometer movements. If the signals are strong the phones can be left in circuit, but if weak they can be removed and the circuits again carefully balanced by means of condenser C_2.*

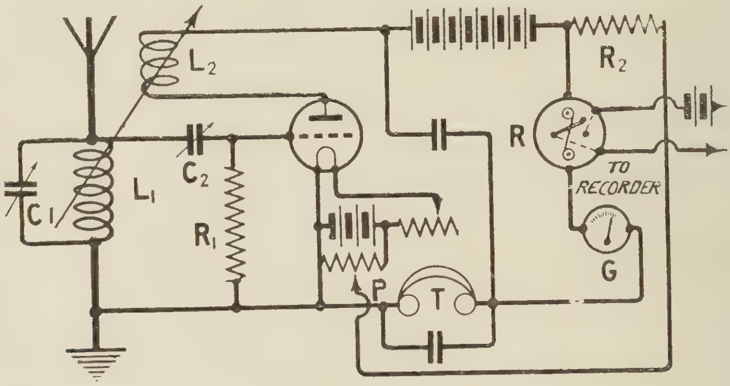


FIG. 192. G. G. Blake's arrangement of a "Zero Shunt" circuit for recording in which the balancing E.M.F. is obtained from the L.T. battery by use of a potentiometer.

TRANSATLANTIC RADIO TELEPHONY (666), (667), (765).—The first transatlantic radio-telephony tests were made in October, 1915, by the American Telephone and Telegraph Company and the International Western Electric Company. On December 14th, 1922,† the same Companies transmitted speech from offices in New York City via seventy miles of land line to the radio station at Rocky Point, Long Island, and thence by radio, to the factory of the Western Electric Company at New Southgate, London, where it was received on a frame aerial (having six feet sides).

A new method was employed. The transmission was accomplished without the presence of the usual carrier wave, the speech being transmitted on one "side band."

* The *Author* has also employed this circuit for operating a relay to record heliographic signals. In this case a high-resistance selenium cell was employed in place of the grid leak, and instead of the circuit from the grid being completed to the negative leg of the filament, connection was made from the selenium cell to a tapping on the H.T. battery.

† It is interesting to note that while the B.B.C. was in the course of formation on November 14th, 1922, the first news bulletin was broadcast from 2 LO and the progress of the General Election was indicated (801).

In ordinary wireless telephony, a carrier wave is employed, which is radiated from the aerial, at a steady frequency all the while, and on this wave the speech frequencies are superimposed. At one instant the frequency of the carrier wave will be increased thereby, and at another instant decreased from its steady normal value ; so that in place of one sharply defined carrier wave, during speech a wave band will be radiated consisting virtually of two side bands, one always above and one below the normal wavelength.

Now, as the carrier wave is itself radiated at one sharply-defined frequency, though its presence is vital, in order to attain telephony, it need not necessarily accompany the speech-frequencies on their journey through space—it can be added to them at the receiving end.

THE SIDE BAND SYSTEM* (981), (982).—The method adopted by the Radio Corporation of America during these tests was as follows :

Only one side band of the complete modulated wave was transmitted instead of both side bands plus the carrier wave (*i.e.* by means of a filter circuit, the carrier wave and one side band were eliminated) (981 and 982).

The above operation was performed at low power. The remaining side band was then amplified by means of water-cooled power valves to about 60 kw., and radiated from the aerial at Rocky Point (this being equivalent to about 250 kw. of the complete modulated wave).

In London the missing carrier wave component was introduced by means of a small local valve oscillator, after which the speech was detected and reproduced in the ordinary way.

The receiving apparatus comprised one oscillator, three ordinary and four extra amplifying valves. Sixty people listened in simultaneously with head 'phones, and a loud-speaker was also employed.

Right from the commencement of the test, every word was clearly intelligible. It is claimed that the new method requires only about one-quarter the power otherwise necessary.

WIRED WIRELESS

WIRED WIRELESS (692), (693), (92), (696), (798), (896), (897), (697), (704), (705), (1041), (1042), (1047–1050), (1073). Reference has already been made to the work of **Hertz, Sir**

* See lecture by **Dr. H. W. Nichols**, at the I.E.E., February 22nd, 1923 (Ref. 765).

Oliver Lodge, and others (692), on the production and detection of stationary electric waves along wires. At that time their possible application was not thought of.

EDISON.—In 1885, as already pointed out in Chapter III., **T. A. Edison**, in his electro-static system of signalling, between moving trains, succeeded in telephoning along existing telegraph lines, while the latter were in use for ordinary traffic, without any mutual interference.*

LEBLANC.—In 1886, still before the day of Hertzian wireless, **Leblanc** laid down the principles of high-frequency current telegraphy and telephony (693).

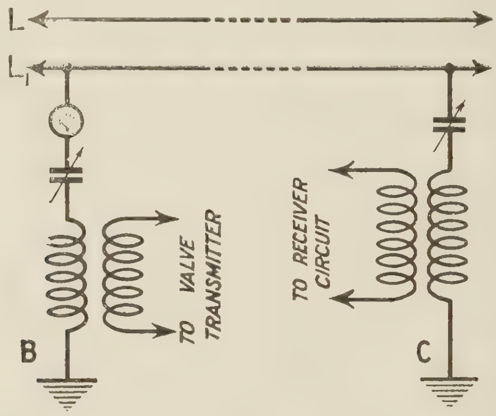


FIG. 193. Diagram showing simple connections for transmission and reception of Wired Wireless.

TURPAIN.—In 1900 **Turpain** (693) developed the idea of communication along wires by guided Hertzian waves.

RÜHMER.—In 1909 **E. Rühmer** successfully provided for the carrying on of three telephonic conversations simultaneously along one wire, employing Poulsen arc transmitters.

SQUIER.—In 1911 **G. O. Squier** (697), (782), (1006),† using an Alexanderson high-frequency alternator, transmitted speech in one direction over a telephone cable eleven kilometres long at the same time that it was carrying ordinary telephone traffic (693), (695), (701), (896), (897). During the War, the U.S.A. Signal Corps, employing an ordinary wireless valve transmitter, succeeded in communicating over considerable lengths of buried bare wires, and also over bare wires submerged in rivers or sea.

* The **Author** in 1908 (Ref. 710) gave a simple method of demonstrating the principles of **Edison's** system, showing how two messages could be transmitted along one wire simultaneously, without mutual interference. For **Edison's** patent see (Ref. 694).

† For a summary of the work of **Squier**, see Refs. (697), (704), and (705).

ERSKINE-MURRAY.—In 1911 **J. Erskine-Murray** patented a method of receiving ordinary radio-telegraph signals, by coupling a receiving circuit to the public telephone lines of a city (709).

DUBILIER COMPANY'S "DUCON."—In 1922 **Wm. Dubilier** applied for a patent for a small condenser called the Ducon,* which, when connected between the electric lighting system of a house and an ordinary valve receiving set, earthed in the usual manner, enabled signals and speech to be picked up without any other aerial.

WESTERN ELECTRIC COMPANY.—During 1917 and 1918 considerable advance was made in "guided wave transmission" over ordinary land wires by the Western Electric Company in America (699), (700), (702), (703), and in Germany to an even greater extent. The latter country possesses one of the most extensive wired wireless installations in existence, and has even erected High-frequency Telephone Exchanges (693), (711). One such line exists between Berlin and Hanover (696).

THE GERMAN "TELEGRAPHEN VERSUCHSAMT."—The German "Telegraphen Versuchsamt" carried out exhaustive experiments in this direction between 1912 and 1918. They devised a system of duplex or multiplex telephony (715) by several superimposed high-frequency currents along telephone lines. They found that these radio-frequency currents damp out in the line very much more than currents at audio-frequencies. This is attributed to losses by radiation, and to skin effects.

When paper-covered cables were employed,† very large dielectric losses occurred.

When cables are employed, having loading coils, each such coil requires to be bridged by a condenser. This system also includes a device for eliminating harmonics (696).

Wired wireless has a very important advantage over ordinary radio-telegraphy and telephony in that far less energy is required in order to transmit to a given distance.

In 1910 **E. Rühmer** devised a multiplex system, employing oscillations at different frequencies simultaneously in line wires (181).

* See also Ref. (1125), (733).

† In 1919 **de Forest** patented a method for using the metallic sheaths of submarine cables for wired wireless (988).

HUTH.—In 1921 **E. F. Huth** (707) devised an ingenious scheme for telephony transmission, along power lines, in which the plate current for the valves is obtained from the same power supply.

In addition to this, the same valve is used for both transmission and for reception, as may be desired, by the employment of a change over switch.

MUIRHEAD.—For army purposes Messrs. Muirhead made use of a buzzer transmitter, working over an ordinary battery telephone system. These sets could be employed in the ordinary network of a city, without causing any interference (92) and they were employed satisfactorily over distances of thirty or forty miles (713).

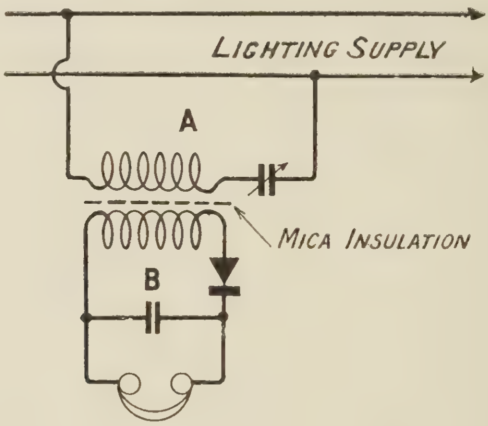


FIG. 193A. Diagram showing connections for crystal reception of Wired Wireless from electric light mains.

Fig. 193 shows a simple set of connections for a wired wireless. L and L_1 are existing telephone lines, carrying ordinary telephonic traffic. L may be a line wire or an earth return. B on the left hand side of the figure shows the connections for transmitting, and C represents the distant receiving circuit.

Fig. 193A shows a simple method " wired wireless " crystal reception (1073). The detector circuit B is tightly coupled to the circuit marked A. The inductances are separated by mica or other suitable insulating material, which will safely withstand the voltage of the mains.

C. E. PRINCE'S ELECTRO-CAPILLARY* CALL DEVICE FOR WIRED WIRELESS (731).—The high-frequency currents at the receiving station are rectified and then passed through a fine thread of mercury in a horizontal capillary tube, balanced at

* Reference should also be made to the Orling Armstrong system, Chapter IX., and to **Orling's** Capillary Relays, later in Chapter IX.

its centre. At each end of the tube is a small cup, containing dilute sulphuric acid, into which contact is made by means of platinum wires. When a rectified current of only two or three micro amperes passes, the mercury moves along the tube, which overbalances, like a seesaw, and, by its movement, closes a local call bell circuit. The unique point of this invention consists of a means provided, of restoring the mercury (and balanced tube) to its original position, whether the call be answered or not.

A well-insulated condenser is placed in series with the capillary tube, and the former stores up the charge when it has passed through the circuit. After the call this charge is released through the mercury and acid in the reverse direction.

This discharge is effected by contacts, which short-circuit the rectifying instruments, when the telephone switch hook is raised ; but supposing the telephone call to remain unanswered the same result is more slowly attained by means of a high-resistance leak.

The British Broadcasting Company's Wired Wireless Achievement in 1922.—On November 3rd, 1922, the following experiments were successfully carried out in connection with a lecture by **E. H. Shaughnessy** at the Regent Street Polytechnic.*

Sir William Noble, then Chairman of the B.B.C., opened the proceedings by a speech from Marconi House, introducing the Lord Mayor of Bristol, whose address was delivered at Bristol. From there it was transmitted by " wired wireless " over the trunk telephone lines to Paddington, and thence to Marconi House by land line. There it modulated the transmitting instruments, and was broadcast far and wide by ordinary wireless.

One of the most striking features of this experiment was that ordinary telephonic communication between London and Bristol went on uninterrupted, and without interfering with the Lord Mayor's speech along the same wires the whole while.

The next item on the programme was a speech delivered from the Guildhall, London, by the then Lord Mayor elect. This was carried by the ordinary telephone wires from the Guildhall to Marconi House, from whence it was broadcast.

*The **Author** made dictaphonic records by wireless, of these speeches, and reproduced them on the occasion of his Presidential Address before the Thames Valley Radio and Physical Association in 1922.

Modern Development of Earth Current Signalling.—(182), (227), (734), (735), (987), (995).—As already stated in earlier chapters, the experimenters in the days before the discovery of Hertzian waves employed earth currents in their attempts at wireless communication. In this connection reference should be made to the work of **Steinheil, Morse, Lindsay, Sir William Preece, Orling, Armstrong, Sharman** (182), and others.

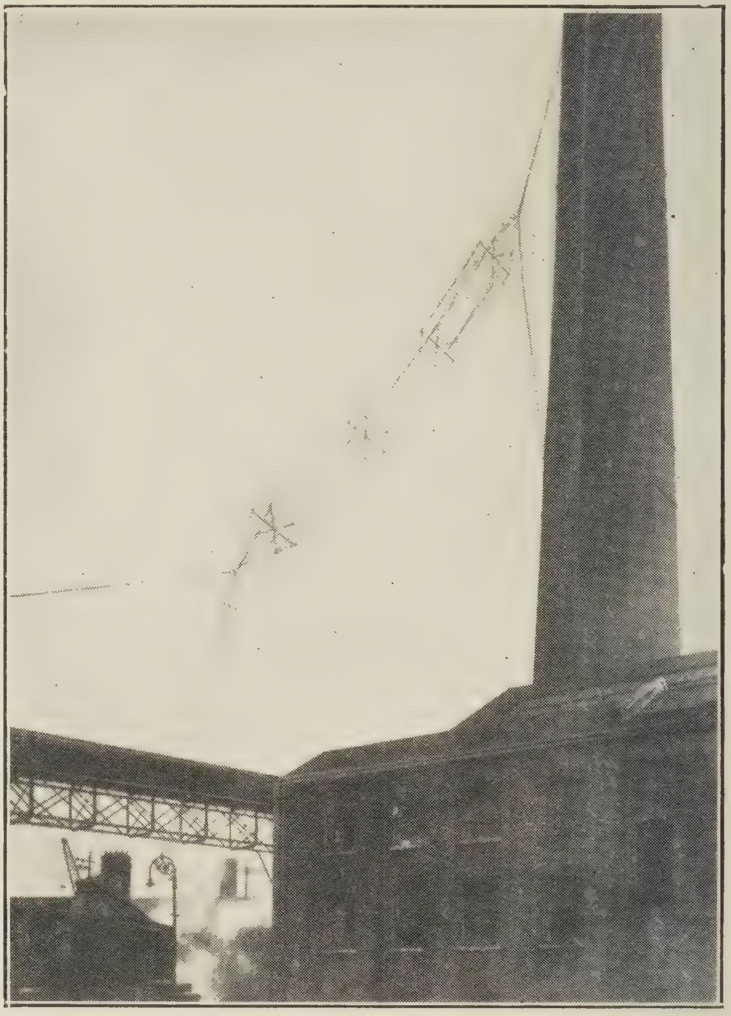


Fig. 194. The Wandsworth Station of the Radio Society of Great Britain (5 W S which was the first Amateur station to transmit across the Atlantic to America.
(*By courtesy of The Wireless Press.*)

For some years earth current signalling fell into disuse owing to the extraordinary advances made in Hertzian methods. During the Great War, however, owing to the impracticability of erecting aerials in the front lines and trenches, and the continued disruption of line wires by shell-fire, etc., it again came into practical use, and not only for signalling between headquarters and the trenches, but it was

employed to intercept messages due to faulty lines, either belonging to the enemy or to ourselves. The advent of valve amplifiers made greater ranges possible than had ever been imagined. Good telegraphy was achieved to a distance of over 2,000 yards, and faint telegraphy as far as 4,000 yards from a power buzzer. Good telephony was carried on to a distance of about 1,500 yards from a valve transmitter. In both these cases the bases were 100 yards long. The adoption of earth signalling by the Allies during the War was mainly due to **Col. Ferrié**, and his staff, at the French Central Bureau de Télégraphie (227).

It has been shown that the ideal arrangement of the bases is attained when the earth connections at either station are made into water, or wet earth, and when there is a comparatively dry and poorly conductive space between them. The earth currents spread outwards in similar manner to the familiar representation of lines of force from the poles of a magnet.

All sorts of improvised earths and connections were employed. Steel pins, or bayonets, were driven into the earth. Biscuit or petrol tins were buried and connected by wires to the instruments. Empty shell cases were used. Also wire netting well covered and trodden into the ground. If a wire fence or stream happened to run in the direction between the transmitting and receiving stations, connection was made to it, and the range was then greatly increased.

The power buzzer or " parleur " employed supplied about 800 pulses of current per second. The ratio of the windings of its transformer was 1 : 15. On 10 volts it took about 2 amps. in the primary when the secondary was delivering 0·2 amps. to an earth base having a resistance of 200 ohms (227).

Larger power buzzers were also used, taking 60 watts in the primary circuit. Some of our best power buzzers were designed by **S. G. Brown.** The German Army employed a buzzer, made by the Deutsche Telephonwerke, Berlin. Signals from this buzzer were read on a 3-valve amplifier, using 150 yards transmitting and receiving bases, at a distance of 4,700 metres (227).

It was found that a high-note buzzer was to be preferred, as it could be more easily read through interfering noises.

Alternating current gives a longer range of signalling than D.C., but the frequency must be kept low. High-frequency currents do not penetrate to any great depths, or spread so far from the base.

In 1917 **Lee de Forest** (987) patented a method of signalling by earth current leakages employing alternating currents and land lines tuned to the frequencies of the currents used.

AN ACCOUNT OF THE FIRST AMATEUR TRANS-ATLANTIC TESTS.——In September, 1920, a request was made by **M. B. Sleeper,** of New York, (647) to the effect that a number of American amateurs, having stations along the Atlantic coast, were anxious to co-operate with British amateurs possessing receiving stations, in the hope of establishing communication between America and England. This request was immediately taken up by **P. R. Coursey**, and all the societies affiliated to the Wireless Society of London* were asked to participate. The wavelength was fixed at 200 metres.

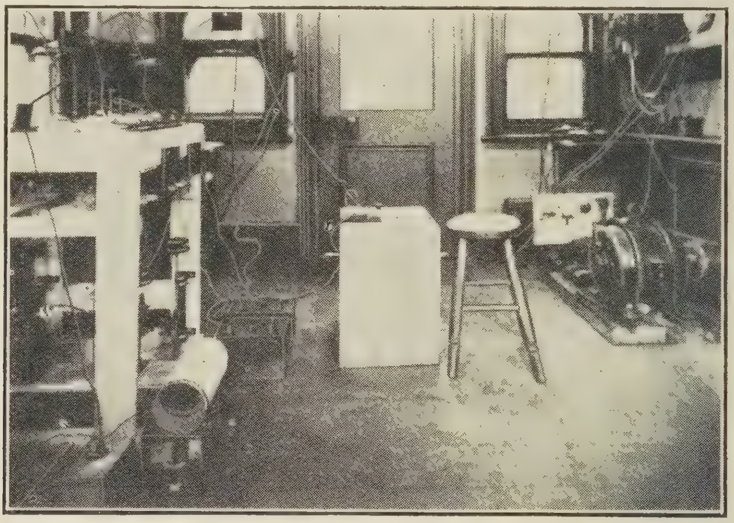


FIG. 195. Interior View of the Wandsworth Station of the Radio Society of Great Britain. (Reproduced from Wireless World by courtesy of the Wireless Press.)

The first series of tests, which took place in the early hours of February 2nd, 4th, and 6th, 1921, were unsuccessful, though 250 amateurs in the United Kingdom had enrolled their names.

In September, 1921, an appeal for further tests appeared (648), proposed by the American Relay League, and again **P. R. Coursey** organised the British amateurs. The tests were arranged to take place from December 8th to December 17th. The majority of the transmissions were to be on 200 metres. A few stations employed 375 metres, while two transmitted on 190 metres. In all seventy-nine American stations took part in the preliminary trials. The tests commenced at midnight, G.M.T., on each occasion, and continued for about six hours.

* This Society is now the Radio Society of Great Britain.

The American amateurs were so enthusiastic that they sent over **P. F. Godley,** with his own receiving equipment (a regenerative receiver and amplifier and an Armstrong super-sonic heterodyne apparatus), to take part in the reception.

The result of these tests was most satisfactory. The signals from America were recorded by eight British amateurs, and by Godley. American signals were also heard at the Hague, Holland, and at Nice, France (653). Signals from five American stations were picked up, complete with correct code words, 1AFV, 1ZE, 2BML, 2FP, and 2ZL, and call-signs were also heard from 1RU, 1UN, 1XM and 2ZC during the tests.

A special station, 1BCG, was erected by the following: **Cronkhite** (in association with **E. H. Armstrong**), **G. Burghard, J. Grinan, W. Inman,** and **Ernest Amy.** The input of this station was 1 kw., and the H.F. output was about 600 watts; it worked on a wavelength of 200 metres. Although this station was allocated definite periods for transmission, it also made additional transmissions to **Godley** over prolonged periods, and very loud signals from it were heard by five of the British competitors. It was also heard in Holland.

Unfortunately, it caused confusion with several of our amateurs, who, recognising it as an American amateur station, took down the repeated calls and messages, hour after hour, during the best nights of the tests, to the complete exclusion of other American amateur signals.

W. R. Burne, of Sale, Cheshire (653), won the first prize. He heard the correct call-signs and code-words of seven different U.S.A. stations, including 1BCG* **H. H. Whitfield,** of Hall Green, Birmingham, heard three stations, with their code words, including 1BCG. Other British amateurs who recorded one or more American stations were: **W. Corsham,** of Willesden; **R. D. Spence,** of Huntley, Aberdeenshire; **A. E. Greenslade,** and **E. McT. Reece,** of Clapham; **J. R. Forshaw,** of Ormskirk, Liverpool; and **T. Cutler,** of Southampton. Signals from 1BCG were first recorded on the morning of December 10th by **P. Godley,** at Ardrossan, near Glasgow, on a Beverage aerial.

The results of each night's receptions were transmitted by the Marconi Company from their Carnarvon radio station,

* For a detailed description of the receiving apparatus employed by the various competitors, see Ref. (654).

and repeated slowly at New Brunswick station, for the benefit of American amateurs.

In 1922 (655) further tests were arranged between English and American amateurs, and the French amateurs also wished to join in.

This time it was decided to transmit from England and France also during the tests. The same arrangements were made with the Marconi Company for sending reports of results from their station at Carnarvon, and the French Committee arranged for their reports to be sent from St. Assise (near Paris), and repeated at Marion station in America. At the end of November, during the period of preparation for the transatlantic tests, quite a number of amateurs from different parts of the country picked up concerts and speech from American broadcasting stations and from amateurs, notably between November 26th and November 27th, at which period atmospheric conditions must have been particularly favourable.

P. R. Coursey was again mainly responsible for the organisation on this side of the Atlantic.*

The test receptions in Great Britain took place from December 12th to December 21st. The results were truly astounding. During these ten days reports were received from forty-seven amateur receiving stations in Great Britain, and from two Dutch stations. The total number of interceptions of U.S.A. and Canadian transmissions reported during this time was 2,297, emanating from sixty different stations across the Atlantic. Some of the received signals came from the Pacific coast. The work of tabulating these astounding successes fell upon P. R. Coursey, with the able assistance of Mrs. Coursey. For a carefully set out series of tables, giving the call letters and addresses of the various American stations, see Ref. (657).

Several British and French amateur stations took part in transmitting, but only one British station was unquestionably heard in America, with verified code words and other messages transmitted. This was the Wandsworth station of the Radio Society of Great Britain 5WS. One French station operated by **Deloy,** at Nice, 8AB, was also authentically received. Reports were received from the operator of a vessel bound from New York to Europe, who first heard 5WS on December

* For programme of American Transmissions, see Ref. (656).

24th, when his ship was 900 miles east of New York (2,500 west of London).

Again, on Xmas. morning, when 2,200 miles from London, he heard 8AB France, also 2SH of Highgate, London, N. On the 26th, when 1,900 miles from London, he received 2OM, Brentford, Middx. On the 27th, at 1,700 miles, he picked up 5WS and 2SH. On the 28th, 5WS was again heard, and on December 30th, when about 1,100 miles away, he received the following British amateur stations: 2AW Wakefield, Yorkshire; 2OM Brentford; 2SH Highgate; 5MS Manchester

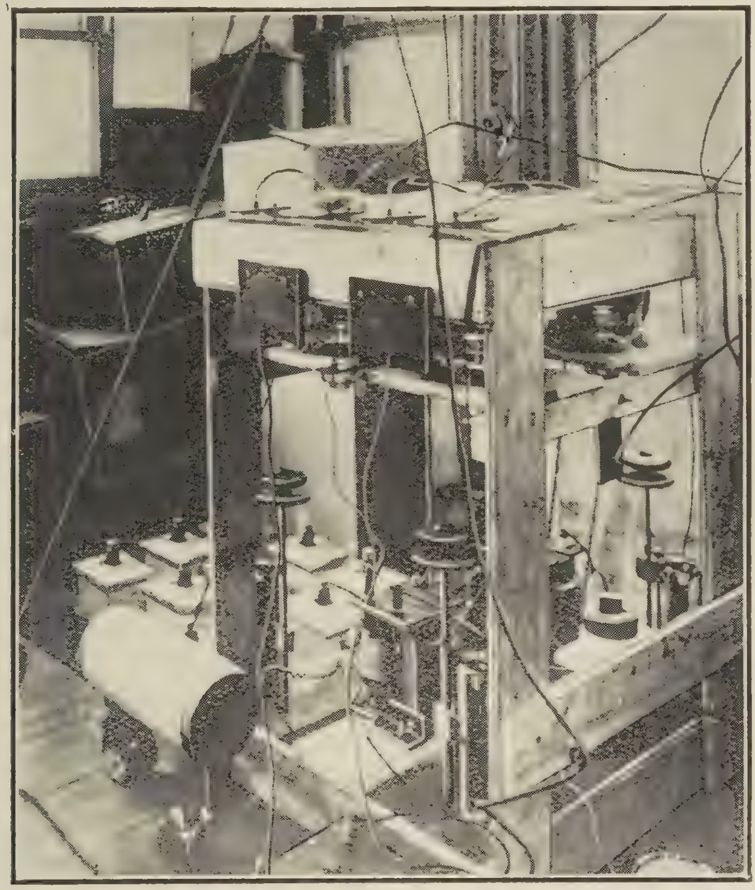


FIG. 196. Is a photograph of the temporally constructed valve panel and controls employed at the R.S.G.B. Station at Wandsworth during the 1922 Transatlantic Tests.

Wireless Society; 5WS Radio Society of Great Britain. Also a French station, 8RRX.

Signals were picked up at Reykjavik, Iceland, on December 24th, from 5WS, including the code word. Also the code word of 2AW.

5WS, the 1-kw. station of the Radio Society of Great Britain, was heard in America by the following stations:—

1BFG. E. B. White, Belfast, Mc.
1BQD. G. M. Mathewson, Newport, RI.

Y

1OR.	Plymouth Radio Club, Plymouth, Mass.
1XP.	L. W. Bishop, Athol, Mass.
1ANA.	R. B. Bourne, Chatham, Mass.
3BEC.	A. M: Young, Radnor, Pav.
2BBB.	G. C. Engel, Ridgewood, N.J.
1MO.	F. S. Schnell, Hartford, Conn.
3ADP.	J. W. Burn, Chester, Pa.

The Wandsworth station of the Radio Society of Great Britain (658) was erected by a specially-appointed sub-committee, including **P. R. Coursey, N. Hamilton, N. Lee, C. F. Phillips, M. Child,** and the **Author.** (Figures 194, 195, 196, and 197).

As our Society had no club-rooms or regular transmitting station we had to find some suitable place. After some difficulty we obtained the loan of a small building at Wandsworth, belonging to the Metropolitan Water Board. This hut adjoins the Wandsworth Generating Station of the County of London Electric Supply Company, and by the courtesy of their chief engineer we were allowed to suspend our aerial from the top of a high chimney stack at their station. The aerial was about 160 feet long and was stretched across a road at the back of the power station and led into the Water Board hut.

The aerial was constructed by M. Child, Hathaway, H. Pickering and E. Trehearne. Owing to the difficulty we had experienced in finding suitable quarters the equipment of the station had perforce to be left to the very last minute, and only by the united efforts of Coursey, Child, Trehearne and the Author, joined on Thursday evening by Hamilton, was the station got into running order in time to participate in the tests. The first transmission from our station was scheduled for 12-45 p.m., December 21st, to 3 a.m., December 22nd, and we just managed to get finished and tuned up in time. Our aerial current on this first occasion was 3 amps. None of our signals on this first night were received in America. We were not altogether surprised, and before we had been informed of our non-success we had already carried out some more tests, and had increased our aerial current to 4·3 amps. After this we got through as before stated. All our tests took place between the hours of midnight and 3 a.m., or on alternate nights between 3 a.m. and 6 a.m., and on these occasions we took it in turns to be on duty two at a time.

Fig. 194 shows a photograph of the aerial, and Fig. 195 is a general view of the interior of our station, showing our 350 cycle rotary converter on the right, and our temporary valve mounting on the left. Fig. 196 is a view of the valve mounting. The circuit employed is shown in Fig. 197 and was suggested by P. R. Coursey.* The valves employed throughout the tests were two U2 rectifying valves and two T4 power valves kindly lent by the M. O. Valve Company. The aerial output from 5WS exceeded the output of 1BCG, the special station erected in America for the 1921 tests.

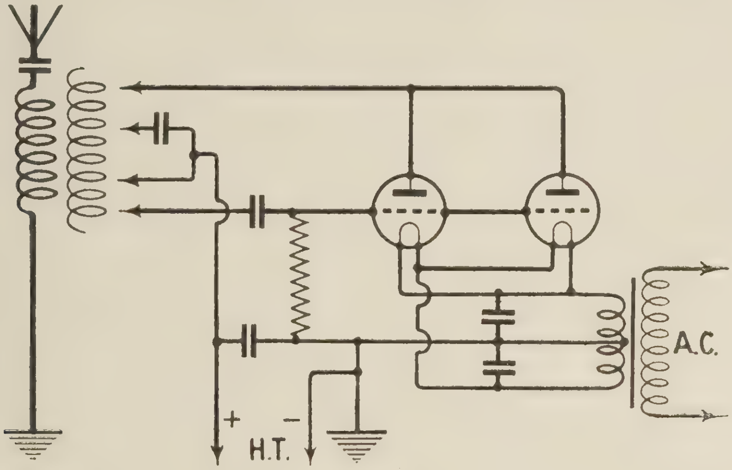


Fig. 197 shows the circuit employed at the Wandsworth Station of the R.S.G.B. during the Transatlantic Tests.

In the winter of 1923 **Leon Deloy** (821), a French amateur, succeeded in getting into touch regularly each night with two Amercian amateurs, **F. H. Schnell** (the Traffic Manager of the American Relay League) and **John L. Reinartz.** Directly after this, on December 8th, one of our English amateurs, **J. A. Partridge,** of Merton, London, called up Deloy, and by his aid got into direct radio communication with Schnell's station in America, and maintained communication until long after daylight on this side of the Atlantic. On the following Sunday night Partridge again got into touch with America and received special messages addressed to the Radio Society of Great Britain, Senatore Marconi, etc. The wavelength employed was in the region of 100 metres.† Since this date numerous other amateurs have repeatedly got into direct touch with America, and by their

* A full account of the apparatus used, and of the tests, was given by **P. R. Coursey,** in a lecture before the Radio Society of Great Britain, on February 21st, 1923 (659); and for a description of 5MS, the station of the Manchester Wireless Society, see Ref. (660).

† On May 30th, 1924, speech was transmitted direct from the Marconi station at Poldhu to Sydney, Australia, on a wave length of about 92 metres. See Chapter XV. Also (819), (820).

work have proved (contrary to expectation for low-power stations) that these short waves are much more efficient for trans-oceanic telegraphy than are those of longer wave length, 200 metres and more, which were at first employed.

Amateur Transworld Tests

On October 16th, 1924, when working on a wavelength of eighty metres, two British amateurs established the world's greatest long-distance record (approximately 11,500 miles). On this occasion **E. J. Symonds** at his station (2OD) at Gerrard's Cross, London, received a message from (Z4AG) in New Zealand. This is the greatest distance which can ever be bridged until possibly communication may be established with some other planet. (It is interesting to note in this connection that it took the United States airship "Shenandoah" seventeen days to cover a distance of 11,000 miles at an average speed of fifty miles per hour. A realisation of this fact gives some idea of the distance bridged.)

As this achievement will always be remembered in the History of Amateur Wireless, a record of the events which followed is quoted below as it appeared in the "Evening Standard" of October 18th, 1924:

> "The following morning, Friday (October 17th), according to a message since received, the signals of G2OD were picked up in New Zealand. On Saturday morning, about 6-15 a.m., the British amateur, Mr. Goyder, who has a set at Mill Hill School, whose call sign is G2FZ, heard distinctly the New Zealand amateur Z4AA calling him in response to a cabled request, and two-way communication was instantly established between the two young men the breadth of the world apart."

Greetings were then transmitted by Mr. Bell (Z4AA) from his station at Waihemo, Dunedin, New Zealand, to the Radio Society of Great Britain, and their receipt duly acknowledged by G2FZ.

Transatalantic Telephony. 1926 tests. (Ref. 1111).—On March 7th, 1926, the G.P.O., working in conjunction with the American Telephone and Telegraph Co., established two way telephonic communication between London and New York.

The voice from London was transmitted from the London Trunk Telephone Exchange in Queen Victoria St., via 80 miles of land line to the G.P.O. radio station at Rugby. There

it was transmitted on a wavelength of 5,770 metres and received at the United States Radio station at Houlton, Maine. From there it was carried by 600 miles of land line to the offices of the American Telegraph and Telephone Co, at Walker Street, New York.

The answering voice came back immediately by another route via 70-mile land line to the Radio Corporation's station at Rocky Point, Long Island, thence by wireless on a wavelength of 5,260 metres to the G.P.O. receiving station at Wroughton near Swindon, and from there by 90 miles of land line to Queen Victoria Street.

It is of great interest to remember that this wonderful achievement took place only 20 years after Fessenden's first achievement of Radio relay work by wireless and land wires. (Refer to page 210 " The work of Fessenden.")

CONCLUSION.

IN case it may be considered by some readers that insufficient prominence has been given to some of the well-known commercial developments of Radio Communication, and too much space devoted to comparatively unimportant details, the Author would point out that his aim and object in writing this Book has been to bring into prominence almost forgotten schemes and devices, in the hope that new ideas may spring therefrom. It is intended to be a History of Principles and Inventions rather than a record of Commercial Wireless. The science of Radio Communication is growing with astounding rapidity. To enumerate the names of all those who have in any way contributed to its development is fast becoming an impossible task. Day by day their number increases, and our knowledge of this subject ripens. Twenty years ago, when one " listened in," whole hours might pass, and not a sound be heard to disturb the Silence of the Infinite, save that caused by an occasional ripple, due to some stirring of Mother Nature, in the form of an atmospheric. Already it is impossible, at any hour of the day or night, to find a time when the silence of the ether is undisturbed by signals, or the music from some distant broadcasting station. In the words of a leader, in one of our daily papers : " It only needs the further application of this Science for all our air (speaking figuratively) to be as full of sweet sounds as ever was that of Prospero's Enchanted Island."

APPENDIX

Appendix A.—G. G. Blake's Triode Receiving Valve Model.
(Reprint of a Lecture* on "A Mechanical Model illustrating the Action of the Three-electrode Valve," † by G. G. Blake M.I.E.E. A.Inst.P. Reproduced by courtesy of the R.S.G.B. and "The Wireless World."

"IN a paper which I read before the Radio Society of Great Britain on March 22nd, 1922, I mentioned a mechanical model which I had constructed to illustrate the action of the three-electrode valve.

Fig. 1 shows the model as it then was. The plate current of the valve is represented by a metal spring, in the centre of which is a small disc of metal which represents the grid voltage of the valve. Through the centre of the spring and disc a piece of thread passes ; this is stretched on a frame. The frame is supported by springs from above and below. When it is made to oscillate up and down its movements may be said to represent the incoming oscillations from a distant transmitting station.

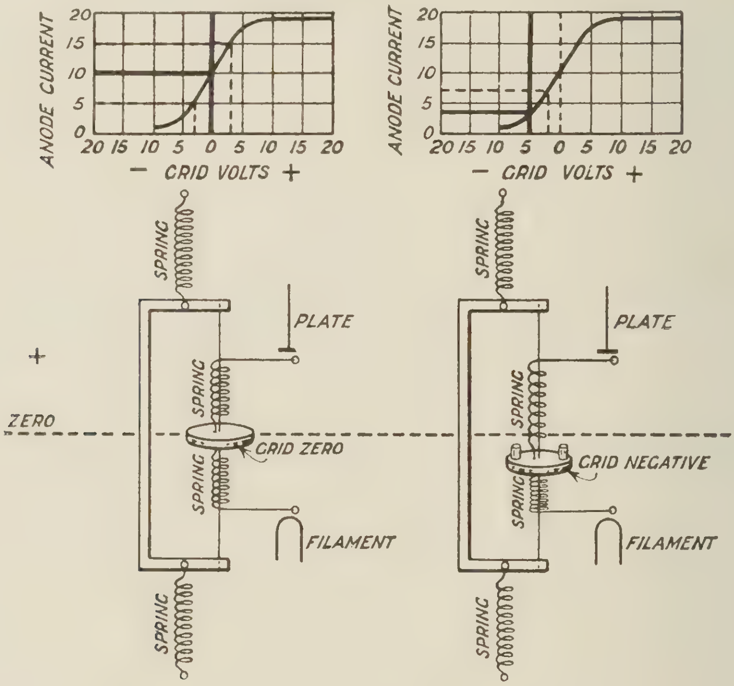


FIG 1.
G. G. Blake's Mechanical Valve Model for instructional purposes (early form).

The thread, as it rubs up and down against the hole in the disc through which it passes, will cause the grid disc to oscillate above and below the zero line, shown in Fig. 1, representing either increase or decrease of grid voltage and plate current.

The left-hand diagram shows the grid functioning at the centre of the characteristic curve of the valve (see curve on left-hand top corner of the figure). In this case the grid disc will oscillate to an equal distance below and above zero line.

If we make the grid of the valve more negative, the right-hand side of Fig. 1 represents the condition of affairs. In this case small weights have been placed on the grid disc to bring it below the zero line, and to represent a negative charge. When the incoming oscillations (represented by the oscillatory movements of the thread) act on the grid,

* *Lecture before the Radio Society of Great Britain, Nov. 22nd, 1922. The Author also described this model before the Wireless Section of the Institute of the Electrical Engineers, Nov. 21st, 1923. (See Journal I.E.E., Vol. 62.)*

† *This model is now employed for instructional purposes in the Royal Air Force and is supplied by Messrs. Cussons, of the Technical Works, Manchester, for class demonstration in colleges and schools.*

the negative pulse has little or no effect, as the lower half of the plate spring is already compressed ; but the positive half of the oscillation takes effect on the grid and increases the plate current. We are now working at the lower bend of the curve represented at the right-hand upper corner of the diagram.

The compressed condition of the plate spring below the grid gives us a method of visualising the increased density of electrons in the space charge of the valve.

I have made several improvements in the construction and applications of this model, which might be of interest.

Fig. 2 is a photograph of the model in its revised form.

Fig. 3 is a lettered diagram of the model. The incoming oscillations are represented by the movement up and down of two arrows, painted red and white, to represent the positive and negative half of each oscillation.

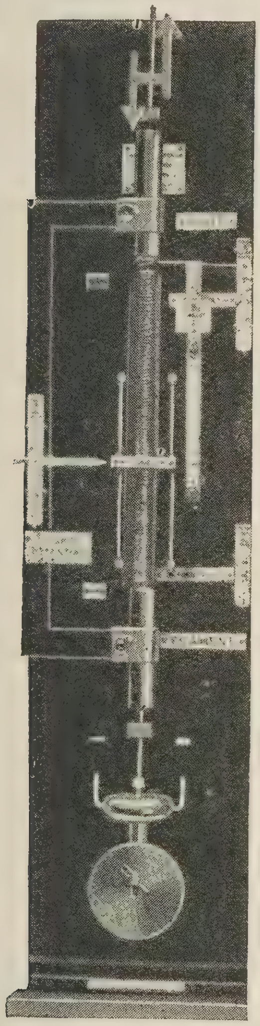


FIG. 2.
Photograph of G. G. Blake's Mechanical Triode Valve Model as used by Royal Air Force for Instructional purposes.

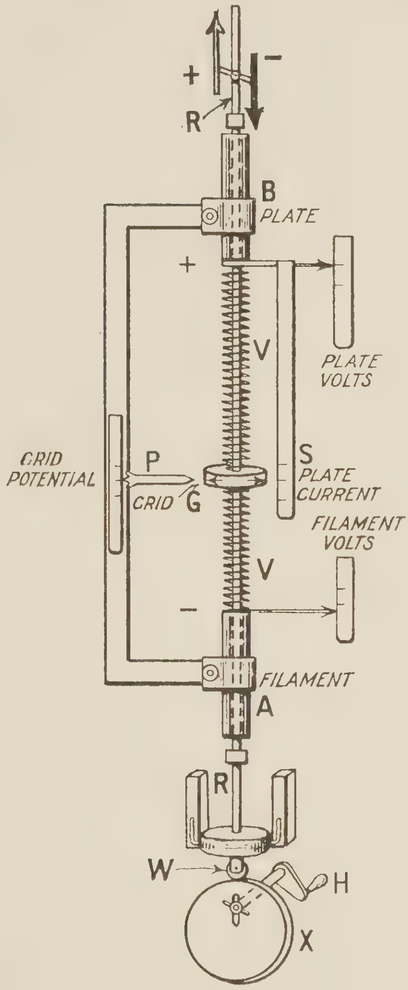


FIG. 3.
Diagrammatic representation of the same Valve Model (note that the eccentric wheel X is rotated by means of a handle H.)

In place of the cotton thread in the old model, a metal rod R passes up through the centre of the spring and disc G. To this the before-mentioned arrows are attached. At the bottom of the rod is a small wheel W which rests on the rim of a second and larger wheel X acting as an eccentric. When rotated by means of a handle H the rod moves up and down through the grid disc G. There is a screw adjustment on this disc (not shown on the figure) to enable us to arrange for the rod to rub more or less lightly against the disc, as it oscillates (representing weak or tight coupling).

The filament and plate are represented by two metal tubes A and B, which hold the plate current spring V. These two tubes can be raised or lowered to represent alterations in the filament voltage and plate voltage. Both are fitted with pointers and scales, indicating the actual voltages which have been worked out from the curves taken from a valve. By means of this model we can repeat all our experiments and show the various readings obtained in the plate current when filament voltage or plate voltage are altered. The plate scale is shown at the top right-hand side of the model, and reads from 33 to 54 volts, and filament scale is to the bottom right-hand side of the model, and reads from 3·5 to 4 volts.

The scale on the left-hand side represents the grid potential, and the pointer can be set either at the same potential as the filament, *i.e.* at zero, or up to 6 volts positive, if it is raised, or down to 6 volts negative if it is lowered.

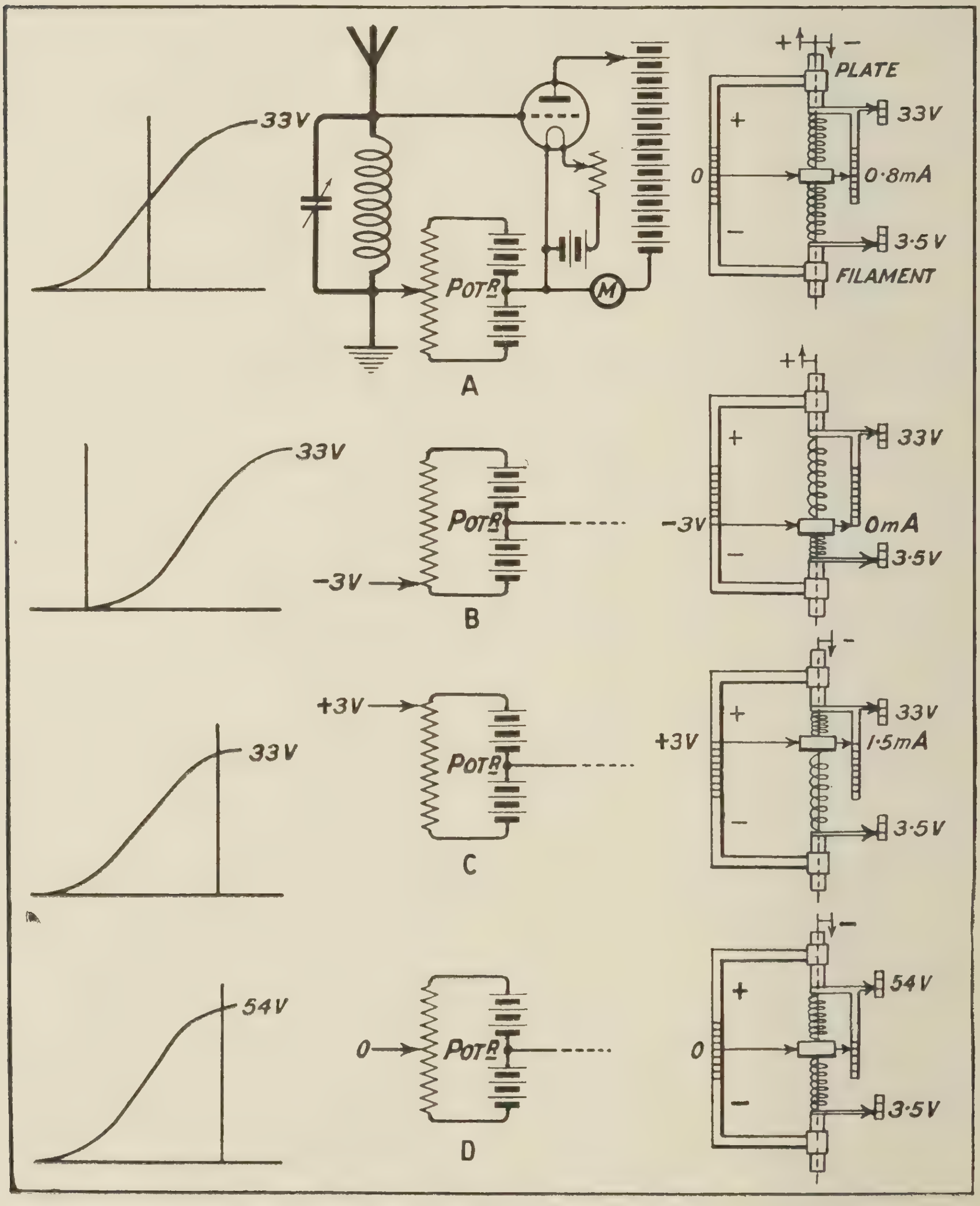


FIG. 4.
Diagram illustrating the method in which G. G. Blake's Mechanical Receiving Valve Model is employed to demonstrate the functioning of a Triode Valve at different points along its characteristic curve.

The amount of plate current at any moment is indicated by the pointer on the grid disc G on plate current scale S, which reads from zero to 2 mA.

It will be noticed that the plate current scale is attached to the plate tube B, and moves up and down with it.

The following experiments, and others, can be mechanically illustrated. (Fig. 4.)

(A.) To illustrate the effect of received oscillations upon the plate current when the valve is functioning near the centre of the straight portion of its curve.

Set grid disc at zero potential	A steady current of 0·8 mA. now passes through the valve.
Set plate at 33 volts	
Set filament at 3·5 volts	

The positive phase of each incoming oscillation produces an increase of 3 volts grid potential, and the negative half oscillation causes a drop to 3 volts negative.

This causes a rise and fall in the plate current between nearly zero and 1·25 mA., so that each half oscillation produces an equal and opposite effect.

(B.) To illustrate the effect of the received oscillations upon the plate current when the valve is functioning at the lower end of its characteristic curve.

Plate voltage and filament voltage remaining the same, make the grid 3 volts negative by setting grid disc (and pointer) at −3 volts	No current passes through the valve.

The positive half of the oscillation increases the plate current, and the negative half does not decrease it.

(C.) To illustrate the valve functioning at the upper end of its characteristic curve.

Plate and filament current remaining constant increase the grid potential to 3 volts positive by raising grid disc (and grid potential pointer)	Plate current now reads 1·5 mA.

The negative phase now diminishes the plate current, but the positive phase does not increase it.

(D.) To show that an increased plate voltage will cause a valve to function at its upper bend.

Set plate at 54 volts	Plate current reads 1·5 mA.
Set filament at 3·5 volts	
with grid at zero potential	

The negative half of the incoming oscillation now reduces the plate current and the positive half oscillation does not increase it, showing that we now have a sufficient positive potential on the plate to cope with all the electrons from the filament, and have reached saturation point.

(E.) To show the amplification factor of the valve by means of the model.

With the grid at zero and the plate potential 54 volts we get a plate current of 1·5 mA.

If we now decrease the plate voltage to 33 volts we shall reduce our plate current when the grid is at zero to 0·8 mA.

We can, however, bring the plate current up to 1·5 mA. again by increasing the grid voltage by only 3 volts positive.

So we see that an increase of 3 volts on the grid is equal to an increase of 21 volts on the plate ; by employing the grid we have obtained a sevenfold amplification."

Appendix B.—R. C. Clinker's Dynamic Transmitting Valve Model. On November 21st, 1923, R. C. Clinker, M.I.E.E., gave a paper * and demonstrated a Dynamic Model of a Transmitting Valve and Circuits. Reproduced by courtesy of the Inventor and the I.E.E.

The electrical circuits are depicted in Fig. 1, and their respective dynamical equivalents in Fig. 2 (reproduced from the Journal of the Institution of Electrical Engineers).

S_1 is a flexible cord which, passing round a system of pulleys 1, 2, 3, 4, 5, 6 and 7, of which Nos. 1, 2, 4, 6 and 7 are pivoted to a base board, and the other two, Nos. 3 and 5, are quite free, and are only held in suspense by the cord. The inertia of the large fly-wheel pulley, No. 4, weighted as desired at W W, represents the inductance L (Fig. 1). The frequency is varied by addition to, or removal from the weights W W. The string S_1 represents the plate current and its motion. It passes up in front of the valve V, the plate and filament of which are represented in painted lines upon the baseboard. A second cord S_2 passes from the centre of pulley 3, over pulleys 8 and 9, and back to the pivot of pulley 5.

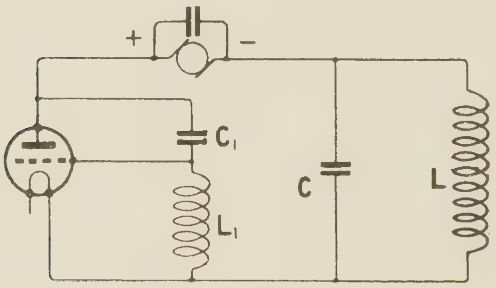


Fig. 1.

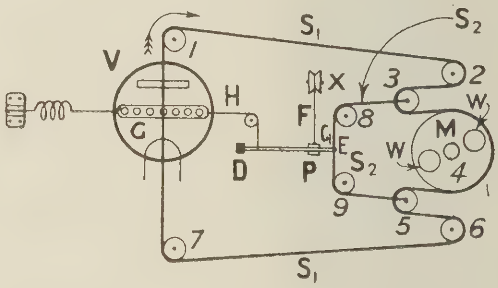


Fig. 2.

Two diagrams illustrating the principle and action of R. C. Clinker's Dynamic Transmitting Valve Model.

The condenser C is represented by a flat spring C, rigidly fixed at D to the baseboard by a suitable clamp, and attached to the string S_2 at E. (When E moves the spring is deflected either upwards or downwards, parallel to the baseboard.) The oscillating circuit comprises the large weighted pulley 4, on ball bearings, the flat spring C, and pulleys 3, 5, 8 and 9, all four of which are also on ball bearings, to reduce friction, which is equivalent to reducing the resistance of the oscillating circuit.

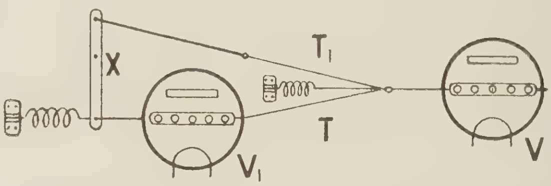


Fig. 3.

Diagram illustrating an addition to R C Clinker's Valve Model for illustrating the " Neutrodyne " principle as suggested by G. G. Blake.

If the string S_1 be restrained from all movement, the spring C and the pulley 4 are still free to oscillate. The D.C. electro-motive force is represented by the pulley 1, which is driven in the direction of the arrow by means of a small motor, not shown in the figure.

A centrifugal governor, similar to that employed to control the speed of a gramophone, is driven from the shaft of pulley No. 1, and the friction-brake controlling the speed of the governor is operated by means of a cord F attached to the spring C at a point P on the " Condenser " spring. (It passes over a pulley-wheel X and then through a hole to the mechanism behind the baseboard.) This cord F acts as the ' coupling " between the grid and the oscillating circuit. This coupling is varied by altering the position of the attachment P, on spring C, and putting it nearer to or further from the end E of the spring. (Fig. 5 is a photograph showing the motor and Governor at back of baseboard.)

* *Before the Wireless Section of the Institution of Electrical Engineers.*

A downward motion of C, *i.e.* a counter clockwise rotation of M, lifts the brake off the governor, and therefore increases the speed of the " plate current " cord S_1. At the same time it displaces a sliding metal strip G (which represents the grid of the valve) a little to the right. This is achieved, as shown, by means of a thread attached to C and G, which passes over a small pulley. This thread is kept taut by means of a spring. This grid displacement uncovers a series of white spots and plus signs, and denotes to the observer that the grid is positively charged. Conversely, an upward movement of the spring C uncovers a series of negative signs.

The action of the model is as follows :

When the motor is suddenly started, string S_1 commences to move in a clockwise direction. The heavy flywheel 4 is unable to respond instantly to this movement, and its lag causes the condenser spring C to be deflected downwards by the string S_2. owing to the lateral displacement of pulleys 3 and 5 (the former is displaced to the left and the latter to the right). This deflection of the spring C, by means of the thread F, releases the governor break and accelerates the speed of string S_1 to a maximum, so that the flywheel 4 rapidly gains speed, and the spring C passes back towards its normal position. When its end E reaches the horizontal position, however, the speed of the flywheel 4, owing to its inertia, is in excess of the speed of the string S_1, which has now been reduced by the application of the regulator brake. Consequently, the end E of the spring C is now deflected above its normal position, and applies the brake more and more, until it eventually stops the motor, and the movement of string S_1 completely. C then

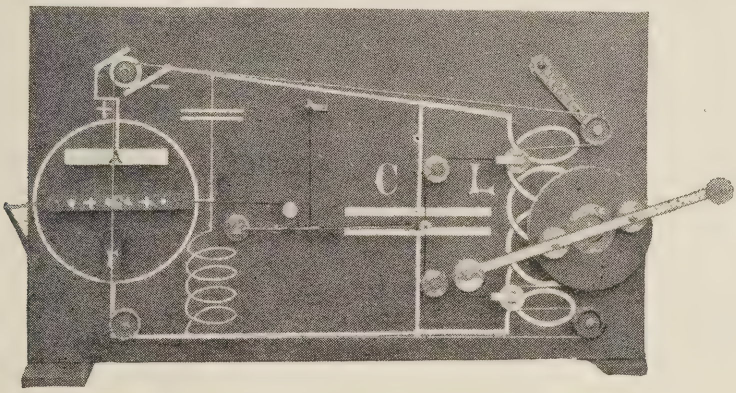


FIG. 4.
Photograph showing front view of R. C. Clinker's Dynamic Transmitting Valve Model. (*Reproduced by courtesy of The British Thomson-Houston Co.*)

returns towards its central position, and the operation is repeated over and over again, *i.e.* continuous oscillation is maintained. The plate current string moves forward in a series of jerky movements, and pulley 4 exhibits an oscillatory motion, superimposed on its undirectional one.

It was pointed out in this paper that by releasing a set-screw holding pulley 1 to its shaft, string S_1 may be freely moved by hand, and the experiments described by *Professor Jenkin* (739), (740)* may be represented as follows :

(1) Applying a low-frequency motion causes the pulley 4 to oscillate, but spring C is not appreciably stressed. This represents the passage of a low-frequency current through the inductance only.

(2) A high-frequency motion passes through almost entirely by means of spring C. That is, a high-frequency current passes through the condenser only.

(3) Slowly reducing the frequency, until the motions of the spring and mass (flywheel 4) are equal, demonstrates " resonance." A small motion of the hand produces a large motion of the spring and mass (flywheel).

" It is very interesting, in this last case, to note how much tension has to be put on the string. This is an excellent illustration of the fact that the impedance of a parallel combination of inductance and capacity is very high at the resonant frequency, if the resistance below. If L C and R be the three constants then the impedance at the resonant frequency is closely equal to L/(CR) ohms, and the combination acts as a resistance

* *See also E. W. Marchant's coupled circuit model* (" *The Electrician,*" *Sept.* 26*th*, 1913) ; *and Dr. Howe's paper at I.E.E. in* 1916 (*Ref.* 766).

having this value. It is seen also that the phases of the currents carried by condenser and coil are nearly in quadrature with their resultant (the external current). This is illustrated by the model, in which careful observation shows that the maximum velocity of the string through the valve (maximum anode current) occurs at the zero of oscillation velocity (or main oscillating current).

Many illustrations in the mechanical field can be given as analogues of the ' negative resistance ' property of a coupled 3-electrode valve."

In a discussion following the demonstration of this valve, the Author* suggested that,

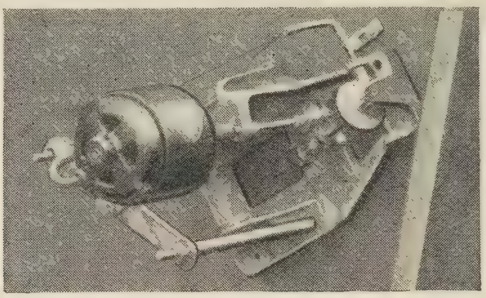


FIG. 5.
Back view of Motor and Governor at back of R. C. Clinker's Valve Model.
Reproduced by courtesy of The British Thomson-Houston Co.

with a very slight addition, this model might be employed to illustrate the " neutrodyne " principle.

A second valve (V_1, Fig. 3) might be coupled by means of an elastic thread T to the valve V of the model (the elastic thread representing the capacity coupling between two circuits due to the internal capacity of the valve). This coupling could then be neutralized by the addition of a second elastic thread T_1, acting in opposite phase, by means of a pivoted arm X.

Another method of illustrating the neutrodyne principle would be to negative the effect of the coupling thread F on the model itself, and so neutralize the coupling between plate and grid circuits.

Appendix C.—Three Circuits due to W. H. Eccles F.R.S. D.Sc. A.R.C.S. M.I.E.E. and shown by him at two lectures delivered at the Royal Institution.

The three diagrams shown in Fig. A, B and C are due to *Dr. W. H. Eccles*.†

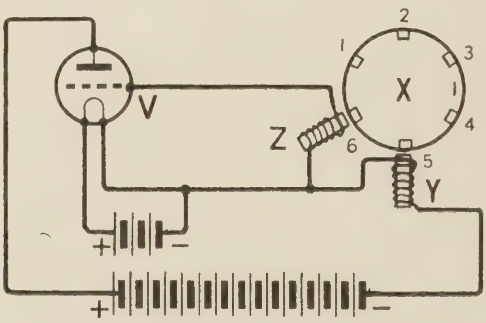


FIG. A.
A D.C. Motor without sliding contacts due to Dr. Eccles.

Fig. A is the first D.C. motor ever shown without any sliding contacts. This was exhibited by Dr. Eccles at a lecture at the Royal Institution on April 24th, 1920. X is an ebonite disc pivoted at its centre. Six soft iron segments, numbered 1 to 6, are fitted,

* *See G. G. Blake's contribution to the discussion* (737).

† *For British patent see Ref.* (1039).

which act as armatures to two electro-magnets, Y and Z. (The magnets employed for this experiment were those from " Brown " telephones.) The disc will revolve at 100 revolutions per second when a voltage of 300 is employed in the plate circuit of valve V.

Fig. B.—The tuning fork T is in this case caused to vibrate by the plate current of valve V_1, and the frequency of the electrical oscillations is controlled in turn by the

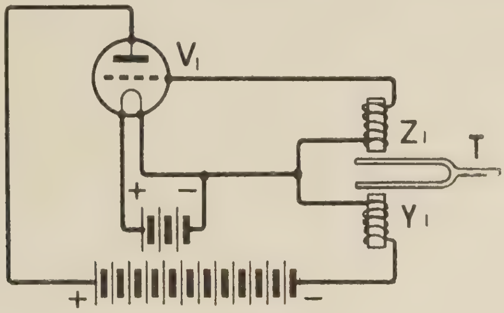


FIG B
W. H. Eccles Tuning Fork Control.

E.M.F. set up in the grid circuit of the valve, owing to the movements of the fork in front of the pole of the electro-magnet Z_1.* The control of the motor, shown in Fig. A, is to be accounted for in a similar manner.

Fig. C is another very pretty little experiment, shown by Dr. Eccles, in a subsequent lecture at the Royal Institution on April 13th, 1923. V_3 is a 2-electrode valve, N.S is a bar magnet, which acts as an armature to two electro-magnets, Z_2 and Y_2. Attached to the centre of this bar magnet is a pendulum U, at the lower end of which is a small rod of sulphur S_1. This is electrified by friction, before the commencement of the experiment. The whole arrangement is pivoted at E.

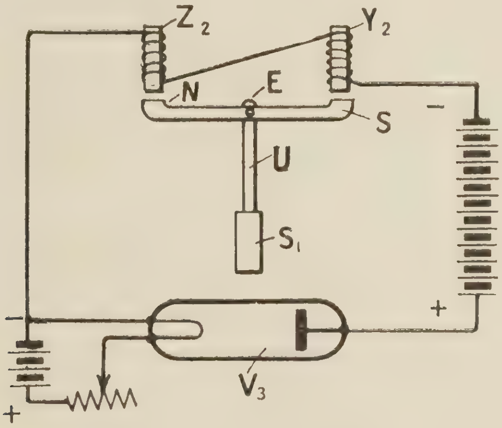


FIG C
Diagram illustrating an experiment shown by W. H. Eccles at Royal Institution in 1923.

The electrified sulphur S acts in place of a grid to valve V_3. When the pendulum swings to the right a plate current flows through the valve and attracts end S of the armature. When the pendulum swings to the left the electrified sulphur repels the electrons from the filament of the valve and reduces the plate current. The oscillations of the pendulum are thus maintained Eguchi Mototaro's " Permanent Electret " (see page 313) might be employed for this demonstration in place of the Sulphur Rod S_1.

* *The principle of this invention has since been employed at Northolt Ref.* (1103), *Rugby and other large wireless stations. The frequency of a valve circuit is maintained at constant value by a tuning fork. A suitable harmonic of it is selected, which, after sufficient amplification, is used to control the wave length of the station.* (*Reference should also be made to frequency control by means of a quartz crystal, Chapter X, page* 154.) *See also British Patent* 155,854 *W. H. Eccles and F. W. Jordan, April* 17*th*, 1918. *Also British Patent* 184,282/1921 *W. H. Eccles* (*covering the use of a master oscillator to control frequency*). *Also, "The Electrician," July* 16*th*, 1926, *pages* 65-72

Appendix D.—The Lodge " N " Circuit or " free oscillator "

Sir Oliver Lodge and E. Robinson have made a very important further invention in connection with the sharp tuning of wireless circuits. It is popularly known as the Lodge " N " circuit.

The following quotation from Provisional British Patent Specification No. 2702/24 (in their joint names) explains the underlying general principle :

" In our Application No. 16038/23, we foreshadowed a freely oscillating tunable circuit which was to serve as connector between a stimulator, such as an aerial, and a

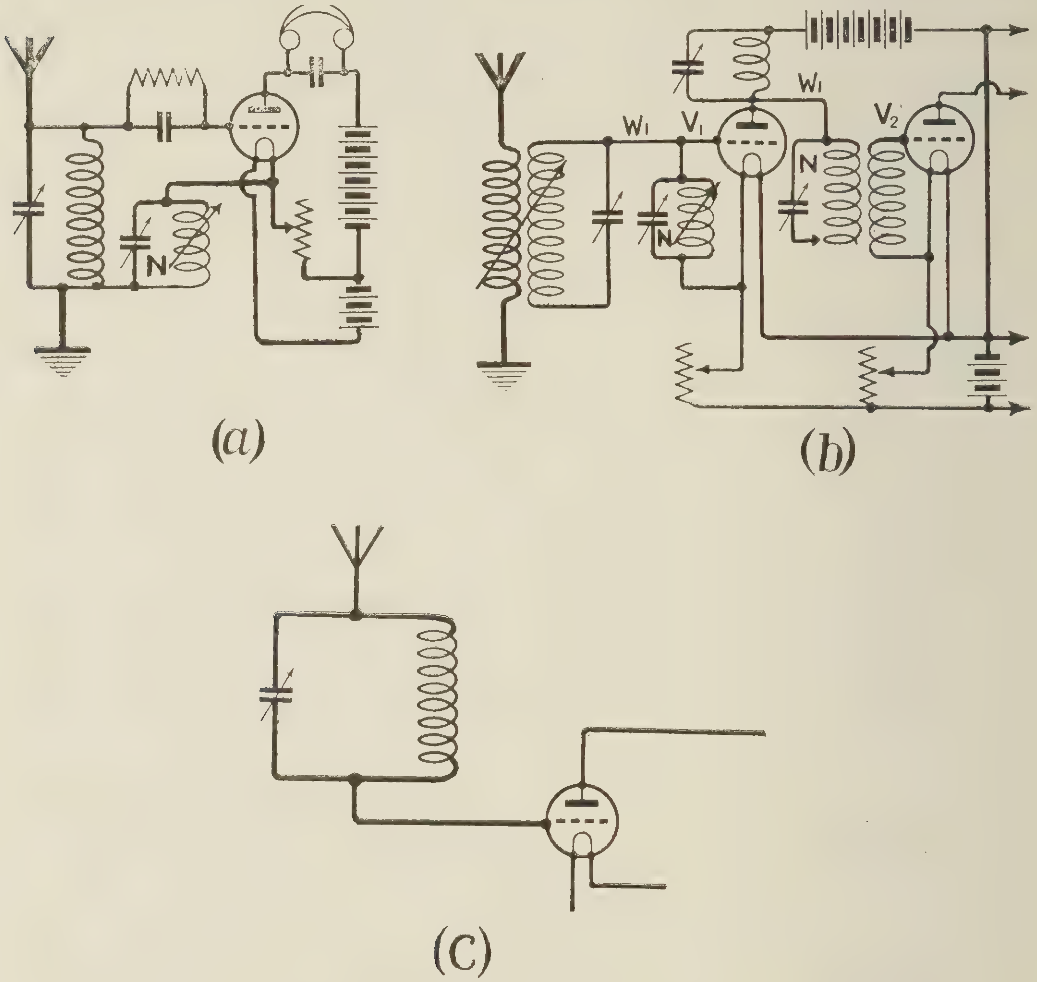


FIG 1. Three Applications of the Lodge "N" circuit as described in Patent No. 223625.

responder, such as a Valve, its object being to reinforce (by resonance) impulses of one definite frequency, and to exclude others. This oscillating circuit was to be interposed in the connection between the stimulating source of oscillations and either the grid or preferably the filament of the Valve, or both."

Figs. 1, A, B and C, illustrating 3 methods in which the " N " circuit may be employed, are taken from British Patent No. 223625 (applied for June 20/23, and accepted complete Oct. 20/24).

The " N " circuit consists of a low resistance tuned circuit between the filament and grid (in cases A and B) of a triode Valve. This circuit may, as in B, be connected by a single wire only to the aerial circuit, and when it is accurately tuned the impulses it receives from the latter build up by sympathetic resonance, to a considerable amplitude and not only give greatly increased selectivity but also very strong articulation without the employment of reaction from the plate circuit.

Fig. 1 A shows a simple arrangement of the circuit between one end of the A.T.I., and one of the filament connections in a simple detector circuit with grid leak and condenser.

Fig. 1B shows the " N " circuit employed to convey impulses from one Valve circuit to another. Valve V1 is employed for H.F. amplification. A single connection wire W suffices to convey the received impulses to the " N " circuit. The amplified impulses are passed on from the plates of V1 to the grid of Valve V2 by means of a transformer, the tuned primary of wh ch constitutes the " N " circuit and has only one connecting wire, W.

In practice it is unusual to employ 2 " N " circuits ; this figure as shown in the patent specification embodies them both, but one or other is usually employed alone.

Owing to the high resistance of triode Valves, the free resonance of the " N " circuit is not disturbed by the former, and it is claimed that for the same reason the " N " circuit can be connected across a crystal detector.

Fig. 1 C is another arrangement of the " N " circuit between an untuned aerial and the grid of a Valve, which can, it is claimed, be employed without an earth connection to any part of the apparatus.

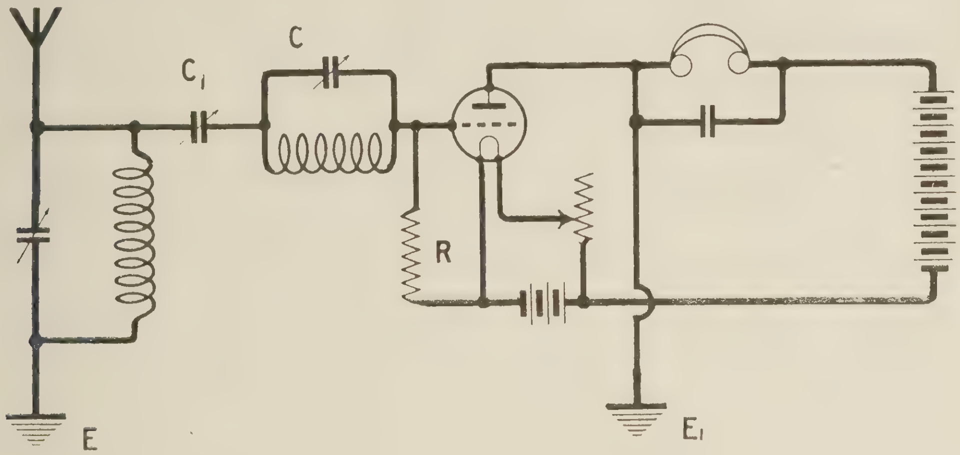


FIG. 2. Shows a circuit due to Melinsky.

Fig. 2 is a later and somewhat similar circuit due to Melinsky.* In this circuit the grid condenser forms a unit in a tuned circuit C1, it is connected to the A.T.I through a variable condenser, and a grid leak R is employed between the grid and filament.

* *Reference should be made to M. M. Melinsky's British Patent, No.* 238003, *applied for May* 8/24, *and completed Aug.* 10/25. *Two other circuits are shown, one for H.F. and one for L.F. amplification.*

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